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THE QUOTA ALLOCATION MODEL: THE LINEAR OPTIMIZATION OF A MARKOV DECISION PROCESS

THESIS

David A. Brown, Major, USAF

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THE LINEAR OPTIMIZATION OF A MARKOV DECISION PROCESS

THESIS

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David A. Brown, B.S.

Major, USAF

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COMMITTEE:	NAME/DEPARTMENT	SIGNATURE
Advisor	Dr. J. T. Moore/ENS	James T. Moore
Reader	Col. T.S. Kelso/EN	TS Kelso
Reader	Dr. J. W. Chrissis/ENS	J. W. [illegible]

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Dave Brown

Table of Contents

List of Figures

Page

List of Tables

Page

Abstract

One of the many needs of the Air Force is advanced technical degrees. These degrees can be acquired in three ways: the Air Force can directly recruit personnel with the required degrees; Air Force personnel can obtain them during off duty time from local civilian colleges near their base; or the Air Force can provide advanced academic degrees (AADs) through the Air Force Institute of Technology (AFIT) or AFIT-sponsored programs.

In 1995, the AFIT Commandant initiated a re-engineering study to review the AFIT mission. One of the initiatives of that study was the Quota Allocation Model (QuAM). The QuAM model is a two-phase mathematical model based on a Markov process that is used to feed a linear optimization. Outputs from the model provide the minimum number of officers, by grade and academic specialty, that must be educated annually to meet the needs and requirements of the Air Force in each of the Air Force education codes. This thesis effort entails: developing a user-friendly tool; migrating the model from lines of FORTRAN 77 code to an Excel spreadsheet environment; highlighting the assumptions necessitated by the Markov decision process; and testing for sensitivity to variations in model input parameters (AAD requirements, attrition, and inventory factors).

THE QUOTA ALLOCATION MODEL:

THE LINEAR OPTIMIZATION OF A MARKOV DECISION PROCESS

CHAPTER I

STATEMENT OF THE PROBLEM

INTRODUCTION

Since the dawn of industry, the human resource manager has struggled with one primary question: How many employees do I need to hire and train yearly to meet the demands for my product and to turn a profit? The answer to that question is based not just on product demand. Other factors contribute significantly to the necessity of keeping a trained force, making this one of management's most difficult questions to answer.

BACKGROUND

Air Force personnel managers are faced with many daunting tasks. Each task is based on meeting the needs of the Air Force in some particular area. One of the needs of the Air Force is personnel with advanced degrees in many technical areas. These degrees can be acquired in three ways: the Air Force can directly recruit personnel with the required degrees; Air Force personnel can obtain them during off-duty time from local civilian colleges near their base; or the Air Force can provide advanced academic degrees (AADs) through the Air Force Institute of Technology (AFIT) or AFIT-sponsored programs.

AFIT was established to provide select officers with specialized technical education based on the needs of the Air Force. It differs from its civilian counterparts in that students can be thoroughly immersed in defense-oriented research and consultation projects (3). The process of determining the number of advanced degree quotas, which should be filled by officers, selecting officers to fill those quotas, and educating the officers requires an extended period of time (30 to 48 months). The entire process, from beginning to end, including time spent in school takes approximately 30 months to produce personnel with a required masters (MS) degree and 48 months to produce personnel with a required doctoral degree (PhD). This extended time period makes accurate forecasting of required numbers of personnel to be selected to attend school and receive AADs essential.

The current process begins with a call for quota from Headquarters Air Force Personnel to the Academic Specialty Monitors (ASMs). The ASM is the key link between the Major Commands (MAJCOMs) and the Air Force Education Requirements Board (AFERB) which prepares quota allocations for AADs. ASMs are also tasked to represent the Air Force-wide functional perspective for degree requirements and for the collection and tracking of information for their designated degree area (15).

The annual quota-call is the signal for the ASMs to collect requests from organizational users, to review, validate, and compile the information, and to present it to the AFERB (15). The AFERB then determines requirements for AADs by education code and forwards them to the Air Force Personnel Center (AFPC). AFPC, working with AFIT, is then tasked with filling the student positions with qualified

personnel that meet the entrance standards of AFIT, as well as the specific requirements for the individual degree program.

This system is constrained by the Air Force in that there is not an unlimited level of resources that can be used for education. The Air Force annually allocates education resources based on a set number of man-years for education. Each MS degree requires 1.5 man-years and each PhD requires 3.0 man-years. Therefore, if 1,000 man-years were allotted, the Air Force could send 666 personnel to get MS degrees, or 333 personnel to get PhD degrees, or some combination of the two (e.g., 450 for MS and 108 for PhD).

The current system has several inherent problems. The system is totally dependent upon the ASM, the users, and the personnel community to adequately forecast the requirements and needs of the Air Force three and four years into the future. The result of this process is that often, too few people are sent to school resulting in Air Force needs going unfilled by way of unmanned AAD billets.

A shrinking education budget and changing attitudes toward formal military funded education have not eliminated the Air Force's need for AADs. The education community, however, has attempted to adjust its programs and size to respond to that ever-changing environment. In 1995, the AFIT Commandant initiated a re-engineering study to review the AFIT mission. One of the initiatives of that study was to develop a quantitative conversion of Air Force personnel requirements into annual flows of educational program entries (3). The result of this initiative was the Quota Allocation Model (QuAM) which is a Markov decision model that feeds a linear program to provide minimum annual flow levels to meet the needs and

requirements of the Air Force for each of the Air Force academic specialty codes. The QuAM model is the launching point for this research.

THE PROBLEM and RESEARCH APPROACH

The QuAM model is a two-phase mathematical model based on a Markov decision process that is used to feed a linear optimization. Outputs from the model provide the minimum number of officers, by grade and academic specialty, who must be educated annually to fill validated AAD billets. Inputs to the model include required AAD billets, by rank and degree level for each Air Force education code, and attrition rates, based on longevity and degree level, and obtained from AFPC historical data (2). The model was originally developed to meet the specific objectives of the AFIT initiative, and was coded in FORTRAN 77 with little or no documentation (7). This research focuses on the QuAM model and entails creating a user-friendly tool. Emphasis is placed on documentation of the model and its assumptions, verification and validation of the model, and enhancing the model's flexibility and adoptability.

Specifically, for ease of use, the model is documented and transported from FORTRAN 77 code to an Excel spreadsheet environment. The assumptions necessitated by the Markov decision process are discussed and validated to provide a baseline understanding of how the model should be implemented. Finally, the model is tested for sensitivity to variations in its three input factors: AAD requirements, attrition, and inventory factor. This sensitivity analysis provides insight into the input factors, and how they affect the model output.

When completed, this research should provide a user-friendly product that is ready for use by Air Force personnel managers. This tool should identify the minimum number of officers that should be educated yearly, in each education code, to meet the needs of the Air Force.

OVERVIEW OF SUBSEQUENT CHAPTERS

Chapter II contains a review of the published literature dealing with personnel models and Markov decision processes. Other areas of review deal with mathematical model verification and validation, concentrating on the area of sensitivity analysis. A quick review of Excel Solver '97 is also included.

Chapter III describes the methodology developed to transport the QuAM (originally called EDFLOW) FORTRAN 77 model to an Excel spreadsheet environment. The design of experiment developed to test for model sensitivity to changes in input factors is also presented along with a methodology on regression analysis.

Chapter IV is a discussion of the results of this research. The spreadsheet model is verified with the original FORTRAN model. The results of the sensitivity analysis are also presented. Chapter V concludes the research and provides recommendations for implementation and further study.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

This thesis effort is centered on the use of the Markovian decision process in personnel modeling. The application of this process to personnel modeling is prevalent in the relevant literature. This chapter briefly reviews some of the literature pertinent to personnel modeling. Dietz's EDFLOW model is also reviewed, along with discussions on sensitivity analysis, experimental design, and Excel '97 Solver.

PERSONNEL MODELS

In the early 1970s, the RAND Corporation proposed that the military personnel system was a close analogy to an actuarial, birth/death model of life expectancy (13). Entry into the military is like *birth* and is made at specific low-level entry points in the hierarchy. All new recruits are essentially undifferentiated, with specialization occurring as a result of training and experience. *Death*, of course, is represented through the many forms of attrition. People leave the military for many reasons. Some leave voluntarily after serving their commitment, others are not promoted and are forced to leave, while a few actually make a career of the military and retire. This birth/death process is the basis for the Markovian decision process.

In a Markov chain, an entity can exist in only one state at any instant of time. Military members enter the chain in the same state and then progress independently from state to state as determined by years of service, promotions, and training gained.

Members are then eliminated from the chain in different states and are replaced by new entries at the initial state. This thus provides a sense of flow through the system.

In the military, the flow of personnel can be thought of as movement from category (grade, years of service, specialty) to category (13). In a Markov process, there must be definition of a meaningful subset of the population (states) from and into which all movement occurs with statistical regularity. In a state, all members of that state are differentiated from all other members on the basis of one or more characteristics. Air Force personnel can transition from grade to grade as they transition from year to year, or they can remain in the same grade year after year.

In 1974, Brothers proposed a Markov methodology that could be used as an aid to determine the force structure of the military (1). His work highlighted the fact that a Markovian model is capable of providing for the many tradeoffs and different controls available to the managers of the system. He emphasized a greater understanding of the use of controls such as recruitment, promotion, and attrition. He concluded that stability in the system and orderly progression could only be accomplished through proper forecasting and through the establishment of accurate manpower requirements.

In 1982, Rish proposed a model to fill AAD requirements for the Civil Engineering career field (20). Although not Markovian in nature, this methodology provided valuable insight into the Air Force personnel system. He noted:

> The Air Force is largely a closed system, promoting from within their ranks and providing almost no lateral entry into senior levels. Advanced education for officers can be obtained only by providing opportunities for mid-career education or by raising the educational and age requirements for entrance to the Air Force to unrealistic and undesirable levels (20:8).

Personnel models can also be considered inventory control models. Fu and Hu's methodology on capacitated production/inventory models (8) can be incorporated into the Markov decision process. They note that when dealing with any production process, tradeoffs must be made between producing too much, leading to excessive inventory, and producing too little, leaving the system unable to meet demand. Their flow control methodology with hedging point has an underlying Markov process. Fu and Hu note that in systems where the inventory is monitored continuously and where the production rate is also controlled continuously, "the optimal policy can be characterized by a single parameter called the hedging point" (8:15). The hedging point parameter is Z. In a flow control problem, if the inventory is less than Z, produce at the maximum rate. If inventory equals Z, then produce at the demand rate. Finally, if inventory is greater than Z, produce zero. Using the assumption of steady-state in the Air Force, or that inventory equals demand, Fu and Hu's methodology would suggest that the Air Force produce at the demand rate. In other words, the Air Force needs to produce just enough AADs each year to fill the billets that will open each year.

Hornestay takes a more modern approach to the personnel problem (10). He advocates effort in three strategic areas: organizing and aligning requirements around mission needs; finding the right person for the right job at the right time; and improved approaches to making employee performance count. His emphasis is to keep personnel from leaving the system at unscheduled points.

THE EDFLOW MODEL

In 1996, Dietz proposed a methodology based on a Markov decision process that was used to feed a linear optimization model (3). This methodology was intended to provide the minimum number of officers, by grade and academic specialty that must be educated yearly to fill validated AAD billets. The mathematical formulation of this methodology is summarized below:

Parameters

$a_{i,d}$ = attrition probability for officers with i years of service and degree level d

$R_{d,g}$ = requirement for officers with degree level d and grade g

γ_d = inventory factor for degree level d (desired ratio of inventory to authorized positions)

Variables

$x_{i,k}$ = number of officers with i years of service and k years graduate education (no action taken)

$x'_{i,k}$ = number of officers with i years of service and k years graduate education (sent to school)

Indices

$i = 0,\ldots, 23$

$d = 0, 1, 2$ (BS, MS, PhD)

$g = 2, 3, 4, 5, 6$ (Lt, Capt, Maj, Lt Col, Col)

$k = 0, 1, 2, 3, 4, 5$ (k represents the number of years of advanced academic education, i.e., 0 = BS, 1 = MS student, 2 = MS, 3 and 4 = PhD student, and 5 = PhD)

Linear Program

The objective of this LP is to minimize the number of personnel sent to school to obtain both MS and PhD degrees. This objective function is this.

$$\text{Minimize } \sum_{i=0}^{21} x'_{i,0} + 2\sum_{i=2}^{20} x'_{i,2} \qquad (2\text{-}1)$$

Subject to:

a. Global Balance Constraints – Ensure that the rate of transition out of any state equals the rate of transition into that state from all other states (3:75), and that the number that start must equal the number attrited plus the number not attrited. There is one global balance constraint for each decision variable (125 total global balance constraints).

$$x_{0,0} + x'_{0,0} = \sum_{i=1}^{22} a_{i,0}\, x_{i,0} + x_{23,0} + \sum_{i=2}^{22} a_{i,1}\, x_{i,2} + x_{23,2} + \sum_{i=5}^{22} a_{i,2}\, x_{i,5} + x_{23,5} \qquad (2\text{-}2)$$

$$x_{1,0} + x'_{1,0} = x_{0,0} \qquad (2\text{-}3)$$

$$x_{j,0} + x'_{j,0} = (1 - a_{j-1,0})\, x_{j-1,0} \qquad j = 2,\ldots,21 \qquad (2\text{-}4)$$

$$x_{j,0} = (1 - a_{j-1,0})\, x_{j-1,0} \qquad j = 22, 23 \qquad (2\text{-}5)$$

$$x_{j,1} = x'_{j-1,0} \qquad j = 1,\ldots,22 \qquad (2\text{-}6)$$

$$x_{2,2} + x'_{2,2} = x_{1,1} \qquad (2\text{-}7)$$

$$x_{j,2} + x'_{j,2} = (1 - a_{j-1,1})\, x_{j-1,2} + x_{j-1,1} \qquad j = 3,\ldots,20 \qquad (2\text{-}8)$$

$$x_{j,2} = (1 - a_{j-1,1})\, x_{j-1,2} + x_{j-1,1} \qquad j = 21,\ldots,23 \qquad (2\text{-}9)$$

$$x_{j,3} = x'_{j-1,2} \qquad j = 3,\ldots,21 \qquad (2\text{-}10)$$

$$x_{j,4} = x_{j-1,3} \qquad j = 4,\ldots,22 \qquad (2\text{-}11)$$

$$x_{5,5} = x_{4,4} \tag{2-12}$$

$$x_{j,5} = (1 - a_{j-1,2})\, x_{j-1,5} + x_{j-1,4} \qquad j = 6,\ldots, 23 \tag{2-13}$$

b. Inventory Demand Constraints – Ensure that all personnel inventory requirements are met. Equations (2-14) through (2-18) ensure BS requirements, (2-19) through (2-23) ensure MS requirements, and (2-24) through (2-27) ensure PhD requirements are met.

$$\sum_{i=0}^{3} x_{i,0} + \sum_{i=2}^{3} x_{i,2} \geq \sum_{d=0}^{2} R_{d,2}\gamma_d \tag{2-14}$$

$$\sum_{i=4}^{10} x_{i,o} + \sum_{i=4}^{10} x_{i,2} + \sum_{i=5}^{10} x_{i,5} \geq \sum_{d=0}^{2} R_{d,3}\gamma_d \tag{2-15}$$

$$\sum_{i=11}^{15} x_{i,0} + \sum_{i=11}^{15} x_{i,2} + \sum_{i=11}^{15} x_{i,5} \geq \sum_{d=0}^{2} R_{d,4}\gamma_d \tag{2-16}$$

$$\sum_{i=16}^{19} x_{i,0} + \sum_{i=16}^{19} x_{i,2} + \sum_{i=16}^{19} x_{i,5} \geq \sum_{d=0}^{2} R_{d,5}\gamma_d \tag{2-17}$$

$$\sum_{i=20}^{23} x_{i,0} + \sum_{i=20}^{23} x_{i,2} + \sum_{i=20}^{23} x_{i,5} \geq \sum_{d=0}^{2} R_{d,6}\gamma_d \tag{2-18}$$

$$\sum_{i=2}^{3} x_{i,2} \geq \sum_{d=1}^{2} R_{d,2}\gamma_d \tag{2-19}$$

$$\sum_{i=4}^{10} x_{i,2} + \sum_{i=5}^{10} x_{i,5} \geq \sum_{d=1}^{2} R_{d,3}\gamma_d \tag{2-20}$$

$$\sum_{i=11}^{15} x_{i,2} + \sum_{i=11}^{15} x_{i,5} \geq \sum_{d=1}^{2} R_{d,4}\gamma_d \tag{2-21}$$

$$\sum_{i=16}^{19} x_{i,2} + \sum_{i=16}^{19} x_{i,5} \geq \sum_{d=1}^{2} R_{d,5}\gamma_d \tag{2-22}$$

$$\sum_{i=20}^{23} x_{i,2} + \sum_{i=20}^{23} x_{i,5} \geq \sum_{d=1}^{2} R_{d,6}\gamma_d \tag{2-23}$$

$$\sum_{i=5}^{10} x_{i,5} \geq (R_{2,2} + R_{2,3})\gamma_2 \quad (2\text{-}24)$$

$$\sum_{i=11}^{15} x_{i,5} \geq R_{2,4}\gamma_2 \quad (2\text{-}25)$$

$$\sum_{i=16}^{19} x_{i,5} \geq R_{2,5}\gamma_2 \quad (2\text{-}26)$$

$$\sum_{i=20}^{23} x_{i,5} \geq R_{2,6}\gamma_2 \quad (2\text{-}27)$$

c. Non-negativity Constraints – Ensure that all variables are non-negative.

$$x_{i,k}\, x'_{i,k} \geq 0 \forall_{i,k} \quad (2\text{-}28)$$

The Markov decision process incorporated by the EDFLOW model requires that several key assumptions be made (3:76; 2):

1. Personnel within an academic specialty are statistically identical and behave independently.
2. The average size and distribution of the overall population within a specialty remains constant.
3. Future attrition probabilities are determined by current longevity and degree level.
4. All graduate programs are completed successfully, i.e., 100% graduation rate.
5. Only educationally qualified personnel with appropriate rank and longevity can satisfy grade requirements.
6. AFPC is 100% effective in assigning personnel with AADs to appropriate billets.
7. Degrees are always valid once obtained.
8. All model parameters are assumed to be constant.

SENSITIVITY ANALYSIS

Once a model is built, it is necessary to analyze the results received. Jackson, Boggs, Nash, and Powell suggest that it is necessary to do more to analyze

computational results than report solution times (11). They recommend the use of statistical analysis and considering the statistical nature of the problem. Even with few results, it is suggested that statistical analysis can provide useful insights and put the results and performance in perspective.

Johnson, Bauer, Moore, and Grant suggest a methodology for sensitivity analysis of the optimal solution, where the right-hand side vector is changed (12). They use response surface methodology that incorporates experimental design and least squares regression to develop a metamodel, and a simple kriging technique to improve their estimate of the objective function value. This methodology is used to predict optimal objective function value based on values of elements of the right-hand side, thus providing a description of the relationship between the right-hand side and the objective function value. This relationship can then provide insights into the behavior of the mathematical programming model.

O'Keefe, Balci, and Smith describe event validity, or sensitivity analysis, as a widely used mathematical model validation technique (18:88). Sensitivity analysis is performed by systematically changing the input parameters over some range of interest and observing the effect on system performance (18:88). Winston defines sensitivity analysis as "observing how changes in a linear program's parameters affect the optimal solution" (23:196). He goes on to list several variations in the problem that should be considered: (1). Change in the cost vector; (2). Change in the right-hand side vector; (3). Change in the constraint matrix.

EXPERIMENTAL DESIGN

There are many ways to approach experimental design. Myers and Montgomery note that an experiment should be efficiently designed to determine which factors are likely to be important in a study (16:10). Such a 'screening experiment' is designed to investigate factors with a view toward eliminating the unimportant ones.

Factorial designs are widely used in experiments involving several factors where it is necessary to investigate the joint effects of the factors on a response (16:79). A special case of factorial designs is the 2^k design where each of k factors of interest has only two levels. With k factors, each replicate of this design has exactly 2^k trials or runs. A 2^k design is especially useful when screening experiments should be performed to identify the important processes or factors (16:79). A 2^k factorial design would include k main effects, k choose 2 two-factor interactions, k choose 3 three-factor interactions,..., up to one k-factor interaction. In all, 2^k designs can determine, through the use of multiple-linear regression, up to 2^k-1 effects (16:103). "These multi-factor investigations permit the analysis of a number of factors with the same precision as if the entire experiment had been devoted to the study of only one factor" (17:1046).

The EXCEL '97 SOLVER

Fylstra, Lasdon, Watson, and Waren note that optimization in Microsoft Excel begins with an ordinary spreadsheet model. "Solver was designed to make optimization an everyday feature of spreadsheets" (9:54). Solver is capable of

incorporating all of Excel's built in functions and can handle up to 200 variables with an unlimited number of constraints (9:33).

To incorporate Solver into a spreadsheet, the user identifies cells that specify an objective function to be optimized and constraints that the objective function is subject to. Cells are also set aside as variables. Solver then analyzes the complete optimization model and produces the matrix form required by most commercial optimizers (9:36). When the *Assume Linear* option is selected, Solver uses a straightforward implementation of the simplex method with bounded variables to find the optimal solution (9:36). Solver then uses the solution values to update the cells within the spreadsheet.

Ragsdale offers four basic guidelines to be followed when formulating a linear programming problem and implementing it in a spreadsheet (19:45):

> 1. Organize the data for the model on the spreadsheet. There are many ways to organize data. The most important thing to accomplish is to organize data so their "meaning and purpose are as clear as possible" (19:45).
> 2. Reserve separate cells in the spreadsheet to represent each decision variable in the model. Any cells can be used, but it is best to arrange these cells in a manner that parallels the structure of the data.
> 3. Create a formula in a cell that corresponds to the objective function in the model. This corresponds to the objective function and will be used by Solver to achieve optimization.
> 4. For each constraint in the model, create a formula in a cell in the spreadsheet that corresponds to the left-hand side of the constraint. Each of these cells must be matched with a cell containing the corresponding right-hand side parameter.

Figure 1 contains a sample spreadsheet model (19:46). The mathematical model associated with Figure 1 is a basic maximization problem. The company involved is simply trying to maximize profits by optimizing the number of each

product built, while meeting the equipment availability constraints. The maximization is formulated as follows:

$$\text{Maximize } 350x_1 + 300x_2$$

Subject to:

$$\begin{aligned} x_1 + \quad x_2 &<= 200 \\ 9x_1 + \quad 6x_2 &<= 1566 \\ 12x_1 + \quad 16x_2 &<= 2880 \\ x_1, x_2 &<= 0 \end{aligned}$$

	Aqua-Spas	Hydro-Luxes		
Number to make:	122	78	Total Profit:	
Unit Profits:	$350	$300	$66,100	
Constraints:			Used	Available
- Pumps Req'd	1	1	200	200
- Labor Req'd	9	6	1566	1566
- Tubing Req'd	12	16	2712	2880

Figure 1: Example of a Spreadsheet Model (19:46)

There is a history for the use of the Markov decision process in personnel modeling. The literature reviewed in this chapter, although not all-encompassing provides the basis for the remainder of this thesis effort. Future chapters expand upon this review, and incorporate many of the formulas and principles suggested.

CHAPTER III

METHODOLOGY

INTRODUCTION

The EDFLOW model, or QuAM as it has come to be known, was originally developed to answer some specific questions and not as a planning tool. It was coded in FORTRAN 77 to run in batch mode and not interactive. This chapter discusses the methodology developed to transport QuAM to an Excel spreadsheet environment. The methodology behind the experimental design used to test the model for sensitivity to changes in its input parameters and cost function is also discussed.

The FORTRAN 77 version of QuAM can be viewed in Appendix A. The code shows that the FORTRAN program calls a data file that contains the input parameters. The main program then manipulates the data into arrays and calls a mathematical programming solver to do the optimization. The results of the main program are then written into an output file that must be called for viewing. To develop a spreadsheet version of QuAM, each of the functions handled by the three individual FORTRAN files must be incorporated into one Excel workbook.

QuAM: The SPREADSHEET VERSION

The EDFLOW model, coded in FORTRAN 77, is not used in any way when moving to an Excel spreadsheet environment. The critical factors needed for creating a user-friendly spreadsheet are the mathematical formulation of the model presented in Chapter II, along with the knowledge of Excel Solver '97 that was also presented.

Recall Ragsdale's four basic guidelines to spreadsheet model development and applies those techniques to the mathematical formulation and Equations (2-1) through (2-28), a user-friendly spreadsheet model should be achievable. The model achieved can then be compared to the FORTRAN 77 implementation as verification of the mathematical processes.

Begin by reviewing the required parameters and variables of the mathematical formulation, so that Ragsdale's guidelines can be applied and the beginnings of a spreadsheet can be formulated:

Parameters

$\boldsymbol{a_{i,d}}$ = attrition probability for officers with i years of service and degree level d

$\boldsymbol{R_{d,g}}$ = requirement for officers with degree level d and grade g

$\boldsymbol{\gamma_d}$ = inventory factor for degree level d (desired ratio of inventory to authorized positions)

Variables

$\boldsymbol{x_{i,k}}$ = number of officers with i years of service and k years graduate education (no action taken)

$\boldsymbol{x'_{i,k}}$ = number of officers with i years of service and k years graduate education (sent to school)

Indices

$\boldsymbol{i}$ = 0,…, 23

$\boldsymbol{d}$ = 0, 1, 2 (BS, MS, PhD)

$\boldsymbol{g}$ = 2, 3, 4, 5, 6 (Lt, Capt, Maj, Lt Col, Col)

$\boldsymbol{k}$ = 0, 1, 2, 3, 4, 5 (BS, MS student, MS, PhD student, PhD student, PhD)

The parameters of attrition, requirements, and inventory factor fall under Ragsdale's first guideline (organize data). The attrition data requires a 3 x 23 block of cells on the spreadsheet, and is based on degree level (See Table1). These cells are laid out with years of service at the top of each column and degree level at the start of each row.

Table 1: Attrition Data Setup

	Year							
d	**0**	**1**	**2**	**3**	**4**	**5**	**…**	**22**
0	$a_{0,0}$	$a_{1,0}$	$a_{2,0}$	$a_{3,0}$	$a_{4,0}$	$a_{5,0}$	…	$a_{22,0}$
1	0	0	$a_{2,1}$	$a_{3,1}$	$a_{4,1}$	$a_{5,1}$	…	$a_{22,1}$
2	0	0	0	0	0	$a_{5,2}$	…	$a_{22,2}$

The requirements data requires a 3 x 5 block of cells on the spreadsheet (See Table 2). These cells are laid out with military grade along the top of each column and with degree level at the start of each row.

Table 2: Requirements Data Setup

	Grade				
d	**Lt**	**Capt**	**Maj**	**Lt Col**	**Col**
0	$R_{2,0}$	$R_{3,0}$	$R_{4,0}$	$R_{5,0}$	$R_{6,0}$
1	$R_{2,1}$	$R_{3,1}$	$R_{4,1}$	$R_{5,1}$	$R_{6,1}$
2	$R_{2,2}$	$R_{3,2}$	$R_{4,2}$	$R_{5,2}$	$R_{g,2}$

The inventory factor requires a 3 x 1 block of cells on the spreadsheet (Table 3).

Table 3: Inventory Factor Setup

BS	γ_0
MS	γ_1
PhD	γ_2

The variables x and x' fall under Ragsdale's second guideline. For ease of use, and to mirror the structure of the attrition data, the variable cells are arranged in an 8 x 24 block on the spreadsheet (Table 4). These cells are also laid out with years of service across the top of each column. Years of advanced education begin each row.

Table 4: Variable Setup

	Year										
k	0	1	2	3	4	5	...	20	21	22	23
0	$x_{0,0}$	$x_{1,0}$	$x_{2,0}$	$x_{3,0}$	$x_{4,0}$	$x_{5,0}$	...	$x_{20,0}$	$x_{21,0}$	$x_{22,0}$	$x_{23,0}$
0	$x'_{0,0}$	$x'_{1,0}$	$x'_{2,0}$	$x'_{3,0}$	$x'_{4,0}$	$x'_{5,0}$	...	$x'_{20,0}$	$x'_{21,0}$	0	0
1	0	$x_{1,1}$	$x_{2,1}$	$x_{3,1}$	$x_{4,1}$	$x_{5,1}$	...	$x_{20,1}$	$x_{21,1}$	$x_{22,1}$	0
2	0	0	$x_{2,2}$	$x_{3,2}$	$x_{4,2}$	$x_{5,2}$	...	$x_{20,2}$	$x_{21,2}$	$x_{22,2}$	$x_{23,2}$
2	0	0	$x'_{2,2}$	$x'_{3,2}$	$x'_{4,2}$	$x'_{5,2}$	...	$x'_{20,2}$	0	0	0
3	0	0	0	$x_{3,3}$	$x_{4,3}$	$x_{5,3}$	...	$x_{20,3}$	$x_{21,3}$	0	0
4	0	0	0	0	$x_{4,4}$	$x_{5,4}$	...	$x_{20,4}$	$x_{21,4}$	$x_{22,4}$	0
5	0	0	0	0	0	$x_{5,5}$	...	$x_{20,5}$	$x_{21,5}$	$x_{22,5}$	$x_{23,5}$

With the basic setup presented in Tables 1–4, the beginnings of a usable spreadsheet formulation of the problem are available. The next thing that needs to be done can be determined from Ragsdale's third guideline: create a formula in a cell in the spreadsheet that corresponds to the objective function in the model (19:45). The objective function for this model is given in Equation (2-1). For this application, however, Equation (2-1) is modified to give the optimal number of man-years annually. This is easily done by multiplying the sum of $x'_{i,0}$ by 1.5 (the man-year cost of an MS Degree) and the sum of $x'_{i,2}$ by 3.0 (the man-year cost of a PhD degree) rather than the respective relative costs of 1.0 and 2.0 that were used in Dietz's original formulation. Because this formulation does not change the original 1:2 ratio,

this change does not affect the optimal annual number of MS and PhD quotas determined. This change is given by:

$$\text{Minimize } 1.5\sum_{i=0}^{21} x'_{i,0} + 3.0\sum_{i=2}^{20} x'_{i,2} \tag{3-1}$$

In order to track MS quotas and PhD quotas separately from man-years, it is necessary to create separate cells in the spreadsheet to accomplish that task. Once those cells are created, it is a simple task to create a cell for the objective function. Table 5 displays one way this can be accomplished.

Table 5: Objective Function

MS Quota	$\sum_{i=0}^{21} x'_{i,0}$
PhD Quota	$\sum_{i=2}^{20} x'_{i,2}$
Man-years	$1.5\sum_{i=0}^{21} x'_{i,0} + 3.0\sum_{i=2}^{20} x'_{i,2}$

To finish the spreadsheet formulation of this function, it is necessary to look at Ragsdale's fourth guideline; namely, for each constraint in the model, create a formula in a cell for both the left-hand side and the right-hand side of the constraint. The constraints for this model are contained in Equations (2-2) through (2-28).

Equations (2-2) through (2-13) specify the global balance constraints. Global balance constraints ensure that the rate of transition out of any state equals the rate of transition into that state from all other states (3:75). There are a total of 125 equality constraints for the global balance portion of the formulation. Equations (2-2) through (2-5) generate the constraints for variables $x_{i,0}$ and $x'_{i,0}$. These equations are listed for reference:

$$x_{0,0} + x'_{0,0} = \sum_{i=1}^{22} a_{i,0}\, x_{i,0} + x_{23,0} + \sum_{i=2}^{22} a_{i,1} x_{i,2} + x_{23,2} + \sum_{i=5}^{22} a_{i,2}\, x_{i,5} + x_{23,5} \quad (2\text{-}2)$$

$$x_{1,0} + x'_{1,0} = x_{0,0} \quad (2\text{-}3)$$

$$x_{j,0} + x'_{j,0} = (1 - a_{j-1,0})\, x_{j-1,0} \qquad j = 2, \ldots, 21 \quad (2\text{-}4)$$

$$x_{j,0} = (1 - a_{j-1,0})\, x_{j-1,0} \qquad j = 22, 23 \quad (2\text{-}5)$$

In order to formulate each of these equations, left-hand side (LHS) and right-hand side (RHS), in its own cell, it is necessary to reserve a 2 x 24 block of cells in the spreadsheet. Table 6 contains one possible formulation for this block of cells.

Table 6: Constraints ($x_{j,0}$ and $x'_{j,0}$)

	Year (*j*)			
Parameter	**0**	**1**	**2,…, 21**	**22, 23**
LHS	$x_{0,0}+x'_{0,0}$	$x_{1,0}+x'_{1,0}$	$x_{j,0}+x'_{j,0}$	$x_{j,0}$
RHS	**RHS (2-2)**	$x_{0,0}$	$(1-a_{j-1,0})x_{j-1,0}$	$(1-a_{j-1,0})x_{j-1,0}$

Equation (2-6) specifies the constraints for the $x_{j,1}$ variables. Equation (2-6) is shown and can be incorporated into the spreadsheet by reserving a 2 x 22 block of cells. Table 7 contains one possible formulation for this block of cells.

$$x_{j,1} = x'_{j-1,0} \qquad j = 1, \ldots, 22 \quad (2\text{-}6)$$

Table 7: Constraints ($x_{j,1}$)

	Year (*j*)
Parameter	**1,…, 22**
LHS	$x_{j,1}$
RHS	$x'_{j-1,0}$

Equations (2-7), (2-8), and (2-9) contain the constraints for the $x_{j,2}$ and $x'_{j,2}$ variables. These equations can be incorporated into the spreadsheet by reserving a

2 x 22 block of cells for formula entry. One possible formulation for these 22 constraints can be seen in Table 8.

$$x_{2,2} + x'_{2,2} = x_{1,1} \qquad (2\text{-}7)$$

$$x_{j,2} + x'_{j,2} = (1 - a_{j-1,1})\, x_{j-1,2} + x_{j-1,1} \qquad j = 3,\ldots, 20 \qquad (2\text{-}8)$$

$$x_{j,2} = (1 - a_{j-1,1})\, x_{j-1,2} + x_{j-1,1} \qquad j = 21,\ldots, 23 \qquad (2\text{-}9)$$

Table 8: Constraints ($x_{j,2}$ and $x'_{j,2}$)

	Year (j)		
Parameter	**2**	**3,…, 20**	**21,…, 23**
LHS	$x_{j,2}+x'_{j,2}$	$x_{2,2}+x'_{2,2}$	$x_{j,2}$
RHS	$(1-a_{j-1,2})x_{j-1}+x_{j-1,1}$	$x_{1,1}$	$(1-a_{j-1,2})x_{j-1}+x_{j-1,1}$

Equation (2-10) generates the 19 constraints containing the $x_{j,3}$ variables. These 19 constraints can be formulated on the spreadsheet by reserving a 2 x 19 block of cells for formula entry. Equation (2-10) is listed for reference, along with one possible formulation for this set of constraints, which is shown in Table 9.

$$x_{j,3} = x'_{j-1,2} \qquad j = 3,\ldots, 21 \qquad (2\text{-}10)$$

Table 9: Constraints ($x_{j,3}$)

	Year (j)
Parameter	**3,…, 21**
LHS	$x_{j,3}$
RHS	$x'_{j-1,2}$

The 19 constraints on the $x_{j,4}$ variables are created by Equation (2-11). Following the same format that has been used throughout this spreadsheet formulation, these constraints require a block of 2 x 19 cells for formula entry.

Equation (2-11) is shown for reference, along with Table 10, which contains one possible formulation for this group of constraints.

$$x_{j,4} = x_{j-1,3} \qquad j = 4,\ldots,22 \qquad (2\text{-}11)$$

Table 10: Constraints ($x_{j,4}$)

	Year (j)
Parameter	**4,..., 22**
LHS	$x_{j,4}$
RHS	$x_{j-1,3}$

The final 19 of the 125 global balance constraints are specified by Equations (2-12) and (2-13). These constraints require that a 2 x 19 block of cells be reserved on the spreadsheet for formula entry. The equations are listed for reference. Table 11 contains one possible way to formulate this block of constraints.

$$x_{5,5} = x_{4,4} \qquad (2\text{-}12)$$

$$x_{j,5} = (1 - a_{j-1,2})x_{j-1,5} + x_{j-1,4} \qquad j = 6,\ldots,23 \qquad (2\text{-}13)$$

Table 11: Constraints ($x_{j,5}$)

	Year (j)	
Parameter	**5**	**6,..., 23**
LHS	$x_{5,5}$	$x_{j,5}$
RHS	$x_{4,4}$	$(1-a_{j-1,5})x_{j-1,5}+x_{j-1,4}$

That concludes the formulation of the global balance constraints. Cells for the inventory demand constraints must now be reserved. Inventory demand constraints ensure that all personnel inventory demands are met (3:75). There are a total of 14 inventory demand constraints. These constraints are specified by Equations (2-14) through (2-27). Notice that these constraints are greater than or equal to constraints

rather than the equalities described by the global balance constraints. This is due to the fact that the RHS describes a minimum requirement that must be met in order to meet inventory requirements. This block of constraints requires that a 14 x 2 block of cells be reserved for constraint formula entry (Table 12).

$$\sum_{i=0}^{3} x_{i,0} + \sum_{i=2}^{3} x_{i,2} \geq \sum_{d=0}^{2} R_{d,2}\gamma_d \tag{2-14}$$

$$\sum_{i=4}^{10} x_{i,o} + \sum_{i=4}^{10} x_{i,2} + \sum_{i=5}^{10} x_{i,5} \geq \sum_{d=0}^{2} R_{d,3}\gamma_d \tag{2-15}$$

$$\sum_{i=11}^{15} x_{i,0} + \sum_{i=11}^{15} x_{i,2} + \sum_{i=11}^{15} x_{i,5} \geq \sum_{d=0}^{2} R_{d,4}\gamma_d \tag{2-16}$$

$$\sum_{i=16}^{19} x_{i,0} + \sum_{i=16}^{19} x_{i,2} + \sum_{i=16}^{19} x_{i,5} \geq \sum_{d=0}^{2} R_{d,5}\gamma_d \tag{2-17}$$

$$\sum_{i=20}^{23} x_{i,0} + \sum_{i=20}^{23} x_{i,2} + \sum_{i=20}^{23} x_{i,5} \geq \sum_{d=0}^{2} R_{d,6}\gamma_d \tag{2-18}$$

$$\sum_{i=2}^{3} x_{i,2} \geq \sum_{d=1}^{2} R_{d,2}\gamma_d \tag{2-19}$$

$$\sum_{i=4}^{10} x_{i,2} + \sum_{i=5}^{10} x_{i,5} \geq \sum_{d=1}^{2} R_{d,3}\gamma_d \tag{2-20}$$

$$\sum_{i=11}^{15} x_{i,2} + \sum_{i=11}^{15} x_{i,5} \geq \sum_{d=1}^{2} R_{d,4}\gamma_d \tag{2-21}$$

$$\sum_{i=16}^{19} x_{i,2} + \sum_{i=16}^{19} x_{i,5} \geq \sum_{d=1}^{2} R_{d,5}\gamma_d \tag{2-22}$$

$$\sum_{i=20}^{23} x_{i,2} + \sum_{i=20}^{23} x_{i,5} \geq \sum_{d=1}^{2} R_{d,6}\gamma_d \tag{2-23}$$

$$\sum_{i=5}^{10} x_{i,5} \geq (R_{2,2} + R_{2,3})\gamma_2 \tag{2-24}$$

$$\sum_{i=11}^{15} x_{i,5} \geq R_{2,4}\gamma_2 \tag{2-25}$$

$$\sum_{i=16}^{19} x_{i,5} \geq R_{2,5}\gamma_2 \tag{2-26}$$

$$\sum_{i=20}^{23} x_{i,5} \geq R_{2,6}\gamma_2 \tag{2-27}$$

Table 12: Inventory Demand Constraints

LHS	RHS
$\sum_{i=0}^{3} x_{i,0} + \sum_{i=2}^{3} x_{i,2}$	$\sum_{d=0}^{2} R_{d,2}\gamma_d$
$\sum_{i=4}^{10} x_{i,0} + \sum_{i=4}^{10} x_{i,2} + \sum_{i=5}^{10} x_{i,5}$	$\sum_{d=0}^{2} R_{d,3}\gamma_d$
$\sum_{i=11}^{15} x_{i,0} + \sum_{i=11}^{15} x_{i,2} + \sum_{i=11}^{15} x_{i,5}$	$\sum_{d=0}^{2} R_{d,4}\gamma_d$
$\sum_{i=16}^{19} x_{i,0} + \sum_{i=16}^{19} x_{i,2} + \sum_{i=16}^{19} x_{i,5}$	$\sum_{d=0}^{2} R_{d,5}\gamma_d$
$\sum_{i=20}^{23} x_{i,0} + \sum_{i=20}^{23} x_{i,2} + \sum_{i=20}^{23} x_{i,5}$	$\sum_{d=0}^{2} R_{d,6}\gamma_d$
$\sum_{i=2}^{3} x_{i2}$	$\sum_{d=1}^{2} R_{d,2}\gamma_d$
$\sum_{i=4}^{10} x_{i,2} + \sum_{i=5}^{10} x_{i,5}$	$\sum_{d=1}^{2} R_{d,3}\gamma_d$
$\sum_{i=11}^{15} x_{i,2} + \sum_{i=11}^{15} x_{i,5}$	$\sum_{d=1}^{2} R_{d,4}\gamma_d$
$\sum_{i=16}^{19} x_{i,2} + \sum_{i=16}^{19} x_{i,5}$	$\sum_{d=1}^{2} R_{d,5}\gamma_d$
$\sum_{i=20}^{23} x_{i,2} + \sum_{i=20}^{23} x_{i,5}$	$\sum_{d=1}^{2} R_{d,6}\gamma_d$
$\sum_{i=5}^{10} x_{i,5}$	$(R_{2,2} + R_{2,3})\gamma_2$
$\sum_{i=11}^{15} x_{i,5}$	$R_{2,4}\gamma_2$
$\sum_{i16}^{19} x_{i,5}$	$R_{2,5}\gamma_2$
$\sum_{i=20}^{23} x_{i,5}$	$R_{2,6}\gamma_2$

The final constraint that must be included in this formulation is Equation (2-28), which is the non-negativity constraint. Ensuring that all of the variables are

non-negative can be handled within Solver itself and does not need to be entered into individual cells of the spreadsheet. This is accomplished by checking *the Assume Non-Negative* option block in the Solver Option Dialogue box (9:36).

Once the parameters (attrition, requirements, inventory factor), variables ($\boldsymbol{x_{i,k}}$ and $\boldsymbol{x'_{i,k}}$), constraints (global balance and inventory demand), and objective function have been entered into the spreadsheet, Solver can be formatted to formulate the optimization. Solver is called by selecting the Tools menu and selecting Solver. When called, the Solver Parameters dialog box is displayed. There are four entries requiring values (9:35):

1. *Set Target Cell*: This is linked to the cell that contains the objective function.
2. *Equal To*: 'Min' should be checked for this formulation.
3. *By Changing Cells*: This is linked to the cells that have been reserved for the variables.
4. *Subject to the Constraints*: Each of the blocks of constraints should be added to the Constraint List box, by using the Add, Change, or Delete buttons.

Once the Solver Parameters have been updated, the Options button should be clicked to get to the Solver Options Dialogue box. On this screen it is necessary to check the *Assume Linear Model* box, the *Assume Non-Negative* box, and the *Use Automatic Scaling* box. The *Assume Linear Model* box determines that the simplex method is used for the optimization (9:36). The *Assume Non-Negative* box places lower bounds of zero on all variables (9:36). When *Use Automatic Scaling* is selected, Solver rescales columns, rows, and RHSs to a common magnitude before beginning the simplex method. Solver then unscales the solution values prior to entering them in the spreadsheet (9:39). One final box that should be looked at on this screen is the *Max Time* box, which controls how long Solver searches for an

answer prior to providing an error message. After updating all required cells, return to the Solver Parameters dialog box and select Solve to engage Solver and search for an optimal solution.

With the basic spreadsheet formulated and with Solver formatted, it is now possible to use a simple Visual Basic for Applications (VBA) subroutine to link the requirement data for each of the 26 individual Academic Specialty Codes (ASCs) into the basic spreadsheet. With this accomplished, Solver can then be called automatically, after each change of requirements. Solver then determines an optimal solution for each ASC. These solutions are then mapped into individual cells in the Excel Workbook for data collection.

SENSITIVITY ANALYSIS

Winston and O'Keefe both describe sensitivity analysis as systematically changing the input parameters of the optimization and observing what happens to the optimal solution. They also stress that changes should be made to both the RHS, and LHS, and finally, the cost vector should be varied to determine the effect of changes on the optimal solution. This systematic changing of the parameters is the topic of this section of research. The objective is to present a methodology that smartly and systematically varies the input parameters of the QuAM model, so that least squares multiple-regression can be performed on the data to determine significant factors.

The input parameters of the QuAM model are *attrition* ($a_{i,d}$), *requirements* ($R_{g,d}$), and *inventory factor* (γ_d). Attrition is a single data set that was derived from AFPC historical data (3:76). The requirements are 26 different data sets, one for each

ASC. The requirements for each ASC are determined and maintained by the individual ASMs (15). There are three inventory factors that are used in this formulation (γ_0, γ_1, γ_2). These inventory factors are built into the model so that requirements "can be scaled up to reflect external factors such as assignment overlaps, career broadening assignments, resident professional military education, operational assignments, etc." (3:76). Basically, these factors allow for additional on-hand inventory to fill requirements.

It is easy to see that the inventory factors can be varied directly in the formulation, just by updating the value stored in the appropriate cell (Refer to Table 3). The problem is how to systematically change the attrition and requirements. To make a constant change to one of these data sets, it is necessary to add a multiplication factor in the formulation of the spreadsheet. This factor when set to 1.0 returns data values at 100 percent. When set to other than 1.0, each member of the data set is multiplied by the factor. A factor of 0.9 produces an across the board decrease of 10 percent, while a factor of 1.1 produces a 10 percent increase in the data values. The introduction of this factor (α for attrition, and ρ for requirement) into the spreadsheet formulation can be seen in Tables 13 and 14. The factor itself can easily be imbedded in any cell within the spreadsheet.

Table 13: Attrition Factor (α)

	Year							
d	**0**	**1**	**2**	**3**	**4**	**5**	**...**	**22**
0	$\alpha a_{0,0}$	$\alpha a_{1,0}$	$\alpha a_{2,0}$	$\alpha a_{3,0}$	$\alpha a_{4,0}$	$\alpha a_{5,0}$	...	$\alpha a_{22,0}$
1	**0**	**0**	$\alpha a_{2,1}$	$\alpha a_{3,1}$	$\alpha a_{4,1}$	$\alpha a_{5,1}$	...	$\alpha a_{22,1}$
2	**0**	**0**	**0**	**0**	**0**	$\alpha a_{5,2}$	...	$\alpha a_{22,2}$

Table 14: Requirement Factor (ρ)

	Grade				
d	**Lt**	**Capt**	**Maj**	**Lt Col**	**Col**
0	$\rho R_{2,0}$	$\rho R_{3,0}$	$\rho R_{4,0}$	$\rho R_{5,0}$	$\rho R_{6,0}$
1	$\rho R_{2,1}$	$\rho R_{3,1}$	$\rho R_{4,1}$	$\rho R_{5,1}$	$\rho R_{6,1}$
2	$\rho R_{2,2}$	$\rho R_{3,2}$	$\rho R_{4,2}$	$\rho R_{5,2}$	$\rho R_{g,2}$

The model now has five factors (α, ρ, γ_0, γ_1, γ_2), which can be systematically changed. When α is changed, changes are initiated only in the LHS of the global balance constraints, which include attrition information. This change to the LHS can be seen by reformatting any of the global balance constraints that include attrition. For example, if all of the variables in Equation (2-4) are moved to the LHS, it is obvious that any change in attrition caused by α only affects the LHS. See Equation (3-2).

$$x_{j,0} + x'_{j,0} - (1 - a_{j-1,0})\,x_{j-1,0} = 0 \qquad j = 2, \ldots, 21 \qquad (3\text{-}2)$$

When ρ, or any γ_d is changed, changes are observed only in the RHS of the inventory demand constraints. This can be verified by looking at any of the 14 inventory demand constraints. In Equation (2-15), notice that changes to either the inventory factor or requirement factor only affect the RHS of the equation.

$$\sum_{i=4}^{10} x_{i,0} + \sum_{i=4}^{10} x_{i,2} + \sum_{i=5}^{10} x_{i,5} \geq \sum_{d=0}^{2} R_{d,3}\gamma_d \qquad (2\text{-}15)$$

With this in mind, QuAM now has five factors that are capable of changing both the LHS and the RHS of the optimization formulation within Solver. These changes are accomplished by changing cells within the spreadsheet, not by changing the format of the optimization programmed within Solver. Cells within the

spreadsheet are easily manipulated through the use of simple VBA subroutines. This makes applying an experimental design easy.

The cost function can also be changed in this formulation. Simply manipulating the formula for the objective function that Solver is using for the minimization can do this changing of the cost function. Using Equation (3-1), there is one cost for MS degrees and one cost for PhD degrees. The goal of this portion of the sensitivity analysis is to see how small changes in the cost function effect the model outputs. It is therefore possible to systematically change Equation (3-1) and possibly observe changes in the optimal solution by using a two-factor (2^2) experiment.

EXPERIMENTAL DESIGN

The goal of experimental design is to efficiently design experiments that will provide some type of useful information (16:12). In this research, the experimental goal is to look for model sensitivity to its input parameters. In other words, the purpose of this portion of the research is to design an experiment that varies the five input parameters and records the model's outputs of MS quota, PhD quota, and man-years. The parameter settings are then incorporated into a multiple-linear regression against the model's output at each of the different factor settings. The results of the regression are then used to determine which factors are significant to each of the outputs.

Recall from Chapter II that a 2^k factorial experiment is a common method used to determine significant factors. In a 2^k factorial experiment, each of the k factors is assigned two levels, low and high, or in the case of a coded variable, -1 and

+1. The purpose of using coded variables in this type of situation is to remove the natural units from the formulation. "Coded variables are usually defined to be dimensionless with mean zero and the same spread or standard deviation" (16:3).

With a total of five input factors, or $k = 5$, this experiment requires 2^5 total runs. With a full run of 32 experiments, it is possible to use multiple-linear regression not only to determine significant main effects, which is the main goal of this research, but also any interaction effects that might be present. One possible 2^5 factorial coded experiment using QuAM's input factors can be seen in Table 15.

Each of the five input variables in this formulation needs to be coded into low and high levels for this sensitivity experiment. The two levels chosen for each of the input variables needs to span their respective expected operating region. This spanning ensures that any conclusions drawn from the regression are valid under normal operating conditions (17:1047).

It is safe to assume that the center or zero point of both α and ρ is at 1.0. Recall that a factor of 1.0 uses the current attrition and requirement data with no changes. Additionally, assuming that both the attrition and requirement data is reasonably stable, a change of +/-10 percent adequately encloses the normal operating region for these factors.

The three inventory factors should never be set below a value of 1.0. With inventory factors set to 1.0, QuAM returns the steady-state number of quotas necessary to maintain the ASC requirement with no excess inventory, or overlap of personnel available. This means at steady-state, the inventory will only support the requirements and ASC attrition. Any other demands, such as resident PME, could not

be met without leaving some requirements unfilled. A reasonable operating range for the inventory factors is 1.0 to 1.5 with the zero point at 1.25. Table 16 defines the coded variables.

Table 15: Coded 2^5 Factorial Experiment

Run #	α	ρ	γ_0	γ_1	γ_2
1	-1	-1	-1	-1	-1
2	-1	-1	-1	-1	1
3	-1	-1	-1	1	-1
4	-1	-1	-1	1	1
5	-1	-1	1	-1	-1
6	-1	-1	1	-1	1
7	-1	-1	1	1	-1
8	-1	-1	1	1	1
9	-1	1	-1	-1	-1
10	-1	1	-1	-1	1
11	-1	1	-1	1	-1
12	-1	1	-1	1	1
13	-1	1	1	-1	-1
14	-1	1	1	-1	1
15	-1	1	1	1	-1
16	-1	1	1	1	1
17	1	-1	-1	-1	-1
18	1	-1	-1	-1	1
19	1	-1	-1	1	-1
20	1	-1	-1	1	1
21	1	-1	1	-1	-1
22	1	-1	1	-1	1
23	1	-1	1	1	-1
24	1	-1	1	1	1
25	1	1	-1	-1	-1
26	1	1	-1	-1	1
27	1	1	-1	1	-1
28	1	1	-1	1	1
29	1	1	1	-1	-1
30	1	1	1	-1	1
31	1	1	1	1	-1
32	1	1	1	1	1

To run this experiment in the QuAM model, it is necessary for the inputs to the model to be natural variables or non-coded. Table 17 shows the corresponding natural values that coincide with the coded variables in Table 15. To run this experiment, it is necessary to update the appropriate cells within the spreadsheet prior to each run of Solver. This cell manipulation is easily accomplished using a VBA subroutine. After Solver determines an optimal solution, appropriate data is recorded prior to the next set of input parameters being loaded. This process continues until each of the 32 runs is completed.

Table 16: Coded Input Variables

Factor	- 1	0	+ 1
α	0.9	1.0	1.1
ρ	0.9	1.0	1.1
γ_0	1.0	1.25	1.5
γ_1	1.0	1.25	1.5
γ_2	1.0	1.25	1.5

Having completed the required runs, any of the common statistical packages, including Excel's Data Analysis Tool Pak (DATP) can be used to run the multiple-linear regression. The coded variables are used as the **X** parameters and MS quota, PhD quota, and man-years are used individually as the **Y** parameter. The goal is to determine factors significant to each of the model's outputs. Therefore, using a 95 percent confidence level, any factor with a P-value less than or equal to 0.05 would be considered significant (17:1243). Figure 2 is an example of an ANOVA table that summarizes the regression results received from DATP. Note that factor γ_0 is not significant to the regression and could be removed.

Table 17: Natural Input Factors

Run #	α	ρ	γ_0	γ_1	γ_2
1	0.9	0.9	1.0	1.0	1.0
2	0.9	0.9	1.0	1.0	1.5
3	0.9	0.9	1.0	1.5	1.0
4	0.9	0.9	1.0	1.5	1.5
5	0.9	0.9	1.5	1.0	1.0
6	0.9	0.9	1.5	1.0	1.5
7	0.9	0.9	1.5	1.5	1.0
8	0.9	0.9	1.5	1.5	1.5
9	0.9	1.1	1.0	1.0	1.0
10	0.9	1.1	1.0	1.0	1.5
11	0.9	1.1	1.0	1.5	1.0
12	0.9	1.1	1.0	1.5	1.5
13	0.9	1.1	1.5	1.0	1.0
14	0.9	1.1	1.5	1.0	1.5
15	0.9	1.1	1.5	1.5	1.0
16	0.9	1.1	1.5	1.5	1.5
17	1.1	0.9	1.0	1.0	1.0
18	1.1	0.9	1.0	1.0	1.5
19	1.1	0.9	1.0	1.5	1.0
20	1.1	0.9	1.0	1.5	1.5
21	1.1	0.9	1.5	1.0	1.0
22	1.1	0.9	1.5	1.0	1.5
23	1.1	0.9	1.5	1.5	1.0
24	1.1	0.9	1.5	1.5	1.5
25	1.1	1.1	1.0	1.0	1.0
26	1.1	1.1	1.0	1.0	1.5
27	1.1	1.1	1.0	1.5	1.0
28	1.1	1.1	1.0	1.5	1.5
29	1.1	1.1	1.5	1.0	1.0
30	1.1	1.1	1.5	1.0	1.5
31	1.1	1.1	1.5	1.5	1.0
32	1.1	1.1	1.5	1.5	1.5

Now that an experiment is designed that varies both the LHS and the RHS, an experiment needs to be designed to look at what happens when the cost function is changed. As discussed previously, the objective function in QuAM has two cost coefficients. Therefore, using the same 2^k methodology already described, $k = 2$, only

four runs are required to accomplish this experiment. Possible designs for this experiment are seen below in Tables 18, 19, and 20. The same regression analysis methodology that was discussed previously is used to evaluate this cost experiment.

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	480.048	96.010	601.726	0.000
Residual	26	4.148	0.160		
Total	31	484.196			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	19.7933	0.0706	280.3084	0.0000	
a	0.7064	0.0706	10.0041	0.0000	
R	1.9793	0.0706	28.0308	0.0000	
γ_0	0.0000	0.0706	0.0000	1.0000	
γ_1	3.1518	0.0706	44.6345	0.0000	
γ_2	0.8069	0.0706	11.4272	0.0000	

Figure 2: DATP ANOVA Table

Table 18: Coded 2^2 Experimental Design

Run #	MS Cost	PhD Cost
1	1	1
2	1	-1
3	-1	1
4	-1	-1

Table 19: Coded Cost Variables

Degree	-1	1
MS	0.5	2.5
PhD	2.0	4.0

Table 20: Natural Cost Variables

Run #	MS Cost	PhD Cost
1	2.5	4.0
2	2.5	2.0
3	0.5	4.0
4	0.5	2.0

QuAM is now transported from FORTRAN 77 to an Excel spreadsheet environment. The final phase of this research is to verify mathematical formulation of the spreadsheet model, using comparison with the original EDFLOW model, and to perform sensitivity analysis experiments that determine significant input parameters. The results of this research are presented in Chapter IV.

CHAPTER IV

RESULTS

INTRODUCTON

The results generated by running the QuAM model with data from each of the 26 ASCs are presented and compared with EDFLOW at two different inventory factor settings. This is accomplished to verify the mathematical formulation of the model. Sensitivity analysis is performed on QuAM, using the 2^5 factorial experimental design developed in Chapter III, to determine the model's sensitivity to the parameters of attrition, requirements, and inventory factor. The cost function is also systematically varied to determine sensitivity to changes in the cost coefficients.

Results for three ASCs (0YEY, 1AGE, and 4Ixx) are presented in detail throughout this chapter. See Appendix D for additional results. The ASCs 0YEY, 1AGE, and the composite ASC 4Ixx are chosen because they are representative of the entire population of 26 ASCs. The 1AGE ASC represents ASCs with a small PhD requirement relative to the MS requirement (less than 10 percent), 0YEY represents those with average requirements for both PhD and MS, and 4Ixx represents those with a large requirement for both PhD and MS. The requirements for each of these ASCs can be seen in Figure 3. The sensitivity analysis results obtained also fall along lines that mirror the three groups represented by the three ASCs chosen.

Requirements (1AGE):						
1AGE	Lt	Capt	Maj	Lt Col	Col	Total
$R_{g,0}$	0	0	0	0	0	0
$R_{g,1}$	17	100	23	4	2	146
$R_{g,2}$	0	5	2	1	0	8
					Total	154
Requirements (0YEY):						
0YEY	Lt	Capt	Maj	Lt Col	Col	Total
$R_{g,0}$	0	0	0	0	0	0
$R_{g,1}$	6	79	40	27	3	155
$R_{g,2}$	0	9	11	12	3	35
					Total	190
Requirements (4Ixx):						
4Ixx	Lt	Capt	Maj	Lt Col	Col	Total
$R_{g,0}$	0	0	0	0	0	0
$R_{g,1}$	92	291	67	18	9	477
$R_{g,2}$	12	50	32	17	2	113
					Total	590

Figure 3: Requirements for 1AGE, 0YEY, and 4Ixx

Typical output of the QuAM model, using inventory factor values of 1.0, can be seen in Figure 4. This output provides MS quota, PhD quota, man-years, and a breakdown of the optimal graduating class. The optimal graduating class is presented by military grade, and provides personnel managers with a class structure that is best suited to meeting the needs of the Air Force in a steady-state environment.

1AGE				ENVIR & ENGINEERING MANAGEMENT		
Optimum: per year!				Optimal Graduating Class Structure		
MS:	16.7	9.3	7.4	0.0	0.0	0.0
PhD:	0.8	0.0	0.8	0.0	0.0	0.0
Man-years	27.6	Lt	Capt	Maj	Lt Col	Col
0YEY				OPERATIONS RESEARCH		
Optimum: per year!				Optimal Graduating Class Structure		
MS:	15.8	4.5	10.1	1.2	0.0	0.0
PhD:	3.5	0.0	1.5	2.0	0.0	0.0
Man-years	34.2	Lt	Capt	Maj	Lt Col	Col
4Ixx				ELECTRICAL ENGINEERING		
Optimum: per year!				Optimal Graduating Class Structure		
MS:	62.4	62.4	0.0	0.0	0.0	0.0
PhD:	10.4	0.0	10.4	0.0	0.0	0.0
Man-years	125.0	Lt	Capt	Maj	Lt Col	Col

Figure 4: Typical QuAM Output

QuAM OUTPUT

The purpose of this section is to verify the mathematical formulation of the spreadsheet based QuAM. This is accomplished by comparison with output from the EDFLOW model. Two separate runs are made with each model. The first run is under conditions where all inventory factors are set to 1.0. Inventory factors of 1.0 are used because Air Force personnel managers require the use of 1.0 inventory factor values in the EDFLOW model, until further research is accomplished to determine appropriate inventory factors. The second run is made with inventory factors set to 1.0, 1.4, and 1.2, respectively, for BS, MS, and PhD. These inventory factor values are chosen due to the fact that the initial EDFLOW formulation was accomplished with the inventory factors set to 1.0, 1.4, and 1.2. Also, the respective factors are well within the normal range discussed in Chapter III, and portray a realistic approach toward personnel modeling.

Results from the first set of runs are presented in Table 21. Notice that MS and PhD quotas are exactly the same for each ASC. Cost in the EDFLOW model is different from the man-years determined in the QuAM model. This is due to the cost coefficient change that was introduced in Equation (3-1).

Table 21: EDFLOW vs. QuAM—Inventory Factors Set to 1.0

ASC		EDFLOW			QuAM		
	R	MS	PhD	Cost	MS	PhD	M-Yrs
1AGE	154	16.7	0.8	18.3	16.7	0.8	27.6
0YEY	190	15.8	3.5	22.8	15.8	3.5	34.2
4Ixx	590	62.4	10.4	83.2	62.4	10.4	124.8

Results from the second set of runs, using inventory factors of 1.0, 1.4, and 1.2, are presented in Table 22. These results also show that the QuAM output is identical to that achieved by EDFLOW. Once again, notice that only determined man-years are different.

Table 22: EDFLOW vs. QuAM—Inventory Factors Set to 1.0, 1.4, and 1.2

ASC	EDFLOW				QuAM		
	R	MS	PhD	Cost	MS	PhD	M-Yrs
1AGE	154	23.2	1.0	25.2	23.2	1.0	37.9
0YEY	190	21.5	4.2	29.9	21.5	4.2	44.8
4Ixx	590	84.1	12.5	109.1	84.1	12.5	163.8

Each of the 26 ASCs programmed into EDFLOW and QuAM was tested and identical results were achieved in every case. EDFLOW and QuAM both determine exactly the same MS and PhD quotas when given identical parameter sets. Therefore, it can be assumed that QuAM, the spreadsheet formulation of EDFLOW, is mathematically identical to its parent model. This means that the same results are now available in a user-friendly, point-and-click, Excel spreadsheet environment.

QuAM INPUT PARAMETER SENSITIVITY

This section of research is dedicated to determining input factors significant to QuAM. The 2^5 factorial experimental design developed previously is used in conjunction with a VBA subroutine (Appendix C) to exercise the experiment and to accomplish the required 32 runs on each ASC. Multiple-linear regression is then accomplished using DATP and a confidence level of 95 percent to determine factors significant to the model. This section presents general results for all ASCs, and

specific results for three individual ASCs that are representative of the entire group of 26 ASCs. The three ASCs presented are 1AGE—Environmental and Engineering Management, 0YEY—Operations Research, and 4Ixx—Electrical Engineering.

The 2^5 factorial experimental design developed in Chapter III (Table 16) is the basis for the sensitivity analysis that is presented in this section of the research. The experiment is programmed using VBA, and is accomplished on each of the 26 ASCs. Typical experiment results are shown in Table 23.

I begin with a big picture look at the sensitivity analysis accomplished on the 26 ASCs. QuAM has three basic outputs that are analyzed (MS quota, PhD quota, and man-years). The outputs are analyzed individually, using the 2^5 factorial experiment (Table 23) and multiple-linear regression.

The purpose of the sensitivity analysis is to determine, through the use of multiple-linear regression and a 95 percent confidence level, which of the five input factors is significant to QuAM's output. The results of this analysis show that QuAM is a stable model that reacts to changes in a strictly linear manner, with no spikes or jumps. Much of the analysis is very straightforward and expected. For instance, γ_0 is not significant to any QuAM output, due to the fact that there is no BS requirement. Another expected result is that $\boldsymbol{R}$ is significant, as long as $\boldsymbol{R}$ is greater than zero, to each output. An example of this can be seen in Figure 5, which contains the 0 (Not significant), 1 (Significant) plot for each ASC output of man-years vs. $\boldsymbol{R}$.

Table 23: Experiment Results (0YEY)

Run #	α	ρ	γ_0	γ_1	γ_2	MS	PhD	M-yrs
1	-1	-1	-1	-1	-1	13.74	3.08	29.86
2	-1	-1	-1	-1	1	15.19	4.64	36.70
3	-1	-1	-1	1	-1	19.17	3.07	37.95
4	-1	-1	-1	1	1	20.61	4.62	44.79
5	-1	-1	1	-1	-1	13.74	3.08	29.86
6	-1	-1	1	-1	1	15.19	4.64	36.70
7	-1	-1	1	1	-1	19.17	3.07	37.95
8	-1	-1	1	1	1	20.61	4.62	44.79
9	-1	1	-1	-1	-1	16.80	3.77	36.50
10	-1	1	-1	-1	1	18.56	5.67	44.86
11	-1	1	-1	1	-1	23.43	3.75	46.39
12	-1	1	-1	1	1	25.19	5.65	54.75
13	-1	1	1	-1	-1	16.80	3.77	36.50
14	-1	1	1	-1	1	18.56	5.67	44.86
15	-1	1	1	1	-1	23.43	3.75	46.39
16	-1	1	1	1	1	25.19	5.65	54.75
17	1	-1	-1	-1	-1	14.76	3.20	31.74
18	1	-1	-1	-1	1	16.22	4.81	38.75
19	1	-1	-1	1	-1	20.68	3.19	40.60
20	1	-1	-1	1	1	22.14	4.80	47.61
21	1	-1	1	-1	-1	14.76	3.20	31.74
22	1	-1	1	-1	1	16.22	4.81	38.75
23	1	-1	1	1	-1	20.68	3.19	40.60
24	1	-1	1	1	1	22.14	4.80	47.61
25	1	1	-1	-1	-1	18.04	3.91	38.79
26	1	1	-1	-1	1	19.83	5.87	47.36
27	1	1	-1	1	-1	25.27	3.90	49.62
28	1	1	-1	1	1	27.06	5.87	58.19
29	1	1	1	-1	-1	18.04	3.91	38.79
30	1	1	1	-1	1	19.83	5.87	47.36
31	1	1	1	1	-1	25.27	3.90	49.62
32	1	1	1	1	1	27.06	5.87	58.19

Other analysis results that are expected include, γ_1 is always significant to MS quota and γ_2 is always significant to PhD quota, as long as the degree requirement is greater than zero. These results can be seen in the 0, 1 plots presented in Figures 6 and 7.

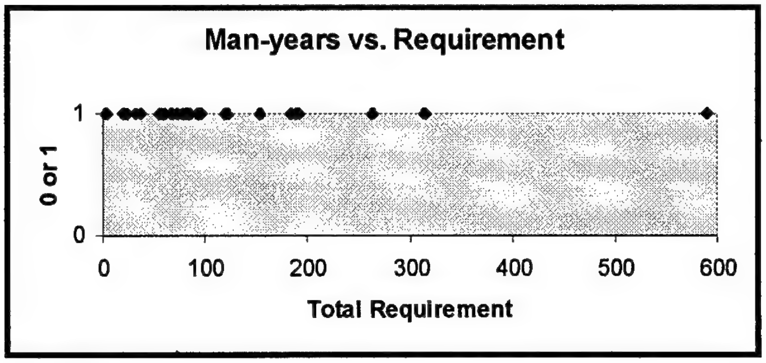


Figure 5: 0, 1 Plot – Man-years vs. Requirement

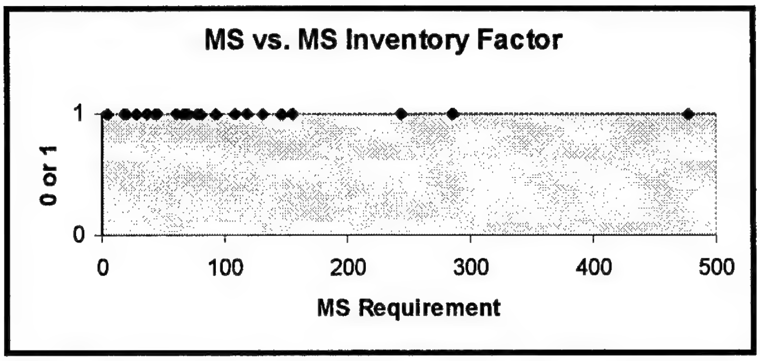


Figure 6: 0, 1 Plot – MS Quota vs. MS Inventory Factor

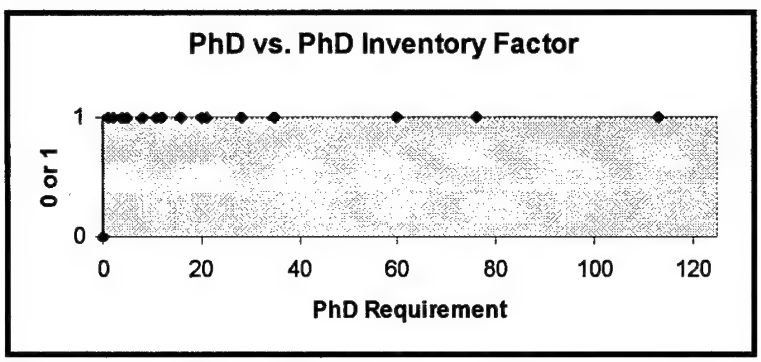


Figure 7: 0, 1 Plot – PhD Quota vs. PhD Inventory Factor

One result that was not expected was the effect of attrition on the model; or as it should be said, the *lack* of attrition effects on the model. Attrition is not a significant input to several ASCs as a whole, and is not significant to many of the individual outputs of MS quota, PhD quota, and man-years. This lack of effect can be

seen in Figures 8, 9, and 10, which display 0, 1 plots for man-years vs. attrition, MS quota vs. attrition, and PhD quota vs. attrition.

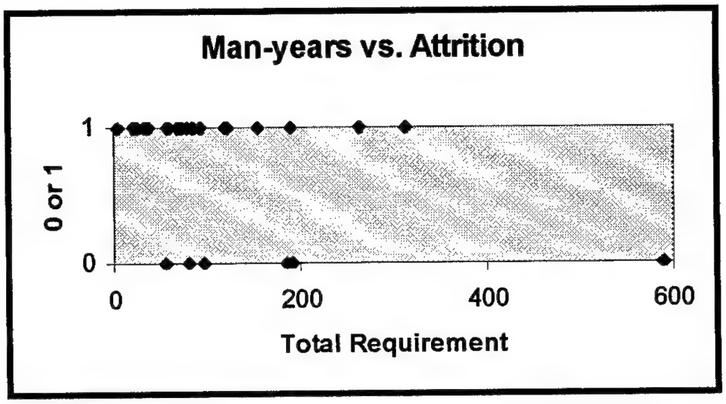


Figure 8: 0, 1 Plot – Man-years vs. Attrition

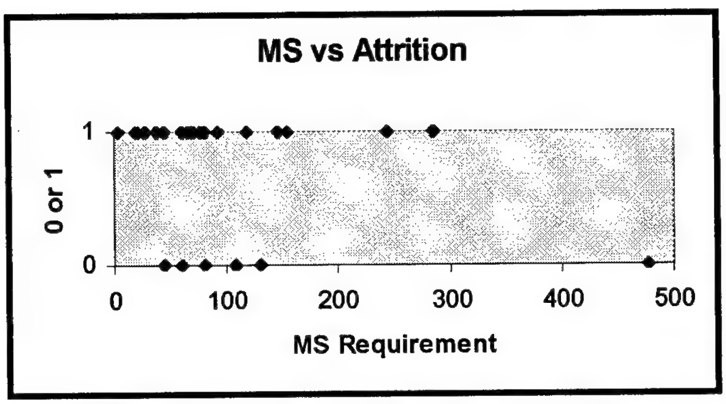


Figure 9: 0, 1 Plot – MS Quota vs. Attrition

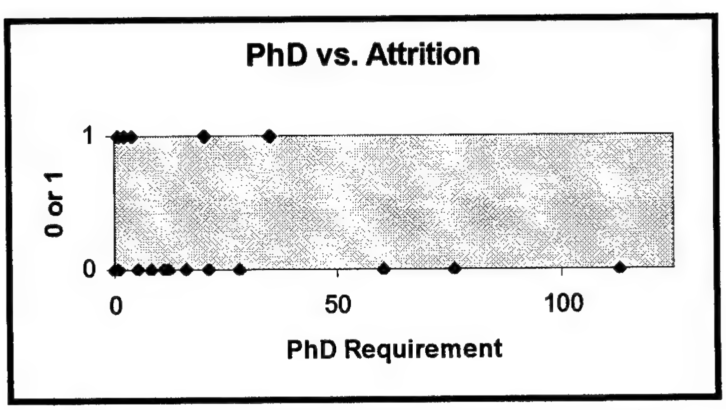


Figure 10: 0, 1 Plot – PhD Quota vs. Attrition

Figures 8, 9, and 10 provide some insight into when attrition is significant to the model. Basically, it can be seen that attrition effect can be broken into three general cases: (1). Attrition is not significant to any ASC output; (2). Attrition is significant to every ASC output; (3). Attrition is not significant to PhD quota, but is significant to man-years and MS quota. The three cases described above, are displayed in the three ASCs chosen as representative of the entire group and are demonstrated in the in-depth analysis of the representative groups.

Having taken a big picture look at the results, now let's look into the details of how those results are determined. Recall that this analysis is based on running a 2^5 factorial experiment on the ASC and then using the experiment results in a multiple-linear regression to determine the significant effects. Case 1 described above, is seen in the 4Ixx ASC. Figure 11 lists the results obtained for the 4Ixx ASC.

4Ixx	Totals	Factors	Man-years	MS	PhD
BS	0	a	0	0	0
MS	477	R	1	1	1
PhD	113	γ_0	0	0	0
	590	γ_1	1	1	0
1 = significant		γ_2	1	1	1

Figure 11: 4Ixx – Significant Factors

The 4Ixx ASC has an MS requirement of 477 personnel and a PhD requirement of 113 personnel for a comparatively large total requirement of 590 personnel with AADs. The large requirement for this ASC is the overriding factor that keeps attrition from being significant. The PhD quota regression results for this ASC are used as an example and are seen in Figure 12. Notice that attrition is not significant to the PhD quota for this ASC. This can best be visualized by looking at the effects plot associated with this regression in Figure 13. Attrition appears as a

horizontal line, confirming that attrition has no effect, and is not significant to the output. It is also clear from both the PhD ANOVA summary output (P-value greater than 0.05 and removed) and the PhD effects plot (horizontal line) that MS inventory factor is not significant to the PhD quota. The MS effects plot for this ASC is shown in Figure 14 to verify that attrition is not significant to MS quota and that both MS and PhD inventory factors are significant.

SUMMARY OUTPUT PHD QUOTA

Regression Statistics	
Multiple R	0.9960
R Square	0.9920
Adjusted R Square	0.9915
Standard Error	0.2748
Observations	32.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	272.4739	136.2370	1804.1525	0.0000
Residual	29	2.1899	0.0755		
Total	31	274.6638			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	13.0519	0.0486	268.6812	0.0000
R	1.3050	0.0486	26.8639	0.0000
γ_2	2.6099	0.0486	53.7274	0.0000

Figure 12: 4Ixx ANOVA – PhD Quota

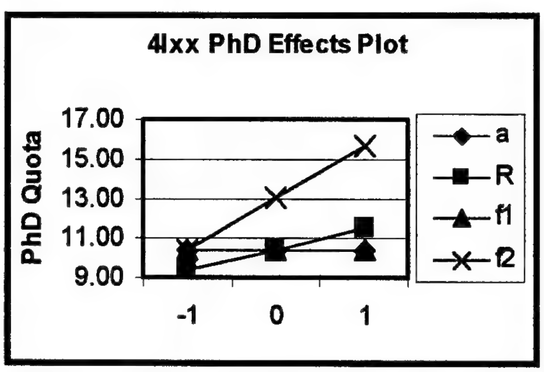


Figure 13: 4Ixx Effects Plot – PhD Quota

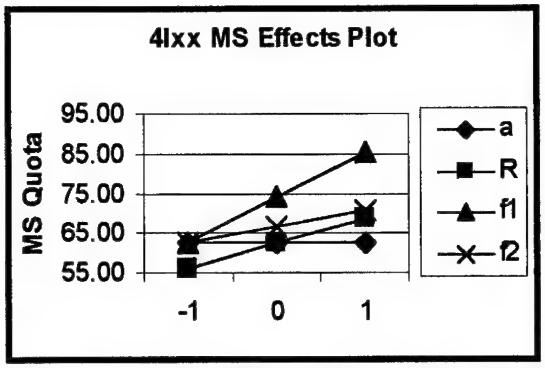


Figure 14: 4Ixx Effects Plot – MS Quota

Case 2, where attrition is significant to each of the ASC outputs is displayed in the 0YEY ASC. Results for the 0YEY ASC are displayed in Figure 15. Notice once again, that ***R*** and γ_2 are both significant to each output, and that γ_1 is significant to both man-years and MS quota. The difference between this and the 4Ixx ASC is that ***a*** is significant to each output.

0YEY	Totals	Factors	Man-years	MS	PhD
BS	0	a	1	1	1
MS	155	R	1	1	1
PhD	35	γ_0	0	0	0
	190	γ_1	1	1	0
1 = significant		γ_2	1	1	1

Figure 15: 0YEY – Significant Factors

The 0YEY ASC has an MS requirement of 155 personnel and a PhD requirement of 35 personnel, for a total requirement of 190 personnel with AADs. This is a medium size requirement for both MS and PhD, with a PhD requirement relative to the MS requirement of greater than 10 percent. The average requirements of this ASC lend attrition some degree of significance. Although, in the ANOVA summary output (Figure 16) ***a*** is significant, it is obvious, by looking at the effects plot for the regression (Figure 17), that ***a*** actually has very little effect on the output. This small effect is noted in the nearly horizontal line on the effects plot. PhD results

are used as an example. The MS effects plot for this ASC is added in Figure 18 to verify that each of the factors, including attrition is significant.

SUMMARY OUTPUT PHD QUOTA					
Regression Statistics					
Multiple R	0.9959				
R Square	0.9918				
Adjusted R Square	0.9909				
Standard Error	0.0957				
Observations	32.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	31.0139	10.3380	1129.2465	0.0000
Residual	28	0.2563	0.0092		
Total	31	31.2703			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	4.3630	0.0169	257.9494	0.0000	
a	0.0810	0.0169	4.7910	0.0000	
R	0.4363	0.0169	25.7949	0.0000	
γ_2	0.8788	0.0169	51.9558	0.0000	

Figure 16: 0YEY ANOVA – PhD Quota

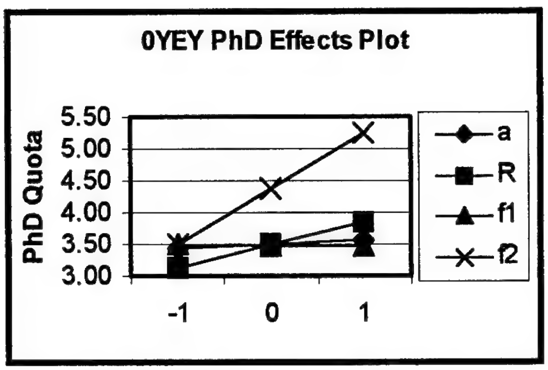


Figure 17: 0YEY Effects Plot – PhD Quota

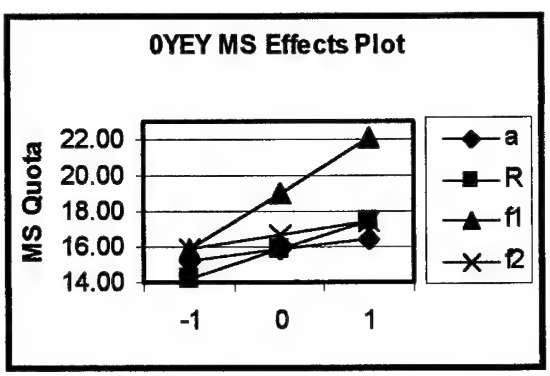


Figure 18: 0YEY Effects Plot – MS Quota

The final case, where attrition is significant to man-years and MS quota but not significant to PhD quota, is evident in the 1AGE ASC. The results for the 1AGE ASC are listed in Figure 19. Once again, ***R***, γ_1, and γ_2 follow what has been demonstrated in each of the preceding examples. However, in this ASC ***a*** is significant to man-years and MS quota but not significant to PhD quota.

1AGE	Totals	Factors	Man-years	MS	PhD
BS	0	a	1	1	0
MS	146	R	1	1	1
PhD	8	γ_0	0	0	0
	154	γ_1	1	1	0
1 = significant		γ_2	1	1	1

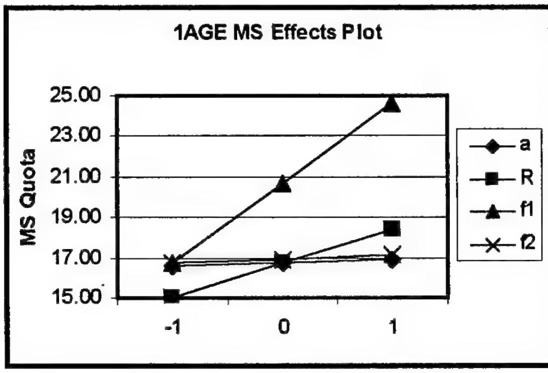
Figure 19: 1AGE – Significant Factors

What needs to be noted is the difference between the MS requirement and the PhD requirement. The MS requirement is almost identical to that of the 0YEY ASC, where attrition is significant to each of the outputs. However, the PhD requirement is small relative to the MS requirement (less than 10 percent). Recall, in Figure 17, that the effect plot for ***a*** is nearly horizontal. The slight difference in PhD requirement eliminates ***a*** as a significant effect for PhD quota.

Figures 20, 21, and 22 show the ANOVA summary for the MS quota, the MS effects plot, and the PhD effects plot for comparison of the ***a*** effect line. Note the P-value for attrition is less than 0.05 (0.0129) meaning that attrition is significant to MS quota. However, when viewed from the perspective of the MS effects plot (Figure 21), notice that the attrition effect is nearly horizontal. This nearly horizontal line signifies that attrition has little effect on MS quota. In the PhD effects plot (Figure 22), the attrition effect is displayed as a horizontal line, meaning that attrition has no effect and is not a significant factor to PhD quota determination.

SUMMARY OUTPUT MS QUOTA					
Regression Statistics					
Multiple R	0.9961				
R Square	0.9921				
Adjusted R Square	0.9910				
Standard Error	0.4354				
Observations	32.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	645.9824	161.4956	852.0751	0.0000
Residual	27	5.1174	0.1895		
Total	31	651.0997			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	20.8879	0.0770	271.4112	0.0000	
a	0.2049	0.0770	2.6628	0.0129	
R	2.0888	0.0770	27.1411	0.0000	
γ_1	3.9671	0.0770	51.5469	0.0000	
γ_2	0.2105	0.0770	2.7353	0.0109	

Figure 20: 1AGE ANOVA – MS Quota



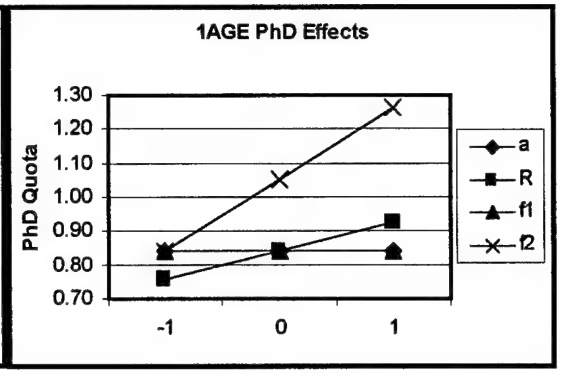


Figure 21: 1AGE MS Effects Plot **Figure 22: 1AGE PhD Effects Plot**

This section demonstrated that the factors R, γ_1, and γ_2 are always significant to the QuAM output. It is expected that requirements are significant to each output, because the requirements are what drive the model to determine a steady-state quota necessary to maintain that particular requirement. The significance of the inventory factors is also expected. The inventory factor is basically just a number used to scale the requirement to maintain a useable inventory of personnel above what is actually needed. Therefore, it makes sense that the MS and PhD inventory factors are significant to QuAM's output.

The effect of a is the main thrust of this section. Attrition, unexpectedly, plays a small role in QuAM output. In the mathematical formulation, attrition is the factor that causes experienced personnel to leave the system and to be replaced by junior personnel entering the system without advanced education or years of service. However, when comparing the small changes made in the LHS by attrition to the large changes made to the RHS by requirement and inventory factor, it becomes obvious that attrition effect is easily overshadowed by the larger effects of requirements and inventory factor. Attrition is not always significant to QuAM's output, as discussed in the three cases above. Even when attrition is a significant factor, its effect on the output of the model is negligible.

QuAM COST COEFFICIENT SENSITIVITY

This section contains a discussion on the sensitivity analysis results obtained by systematically varying the cost coefficients of the objective function [Equation (3-1)]. A 2^2 factorial design is used, as was previously developed in Chapter III (Tables 18, 19, and 20). Results of one representative ASC are presented and discussed in detail. One ASC is used, due to the fact that each of the ASCs display the same behaviors when cost coefficients are varied.

Recall, in Equation (3-1), that the objective function for QuAM has a man-year cost associated with MS quota and a man-year cost associated with PhD quota. With just two cost coefficients to vary, a simple 2^2 factorial experiment is used to determine model sensitivity to changes in the cost function. This methodology is developed in Chapter III. The experiment used is presented in Table 18. Typical

results for this experiment are displayed in Table 24. Notice that an additional run is made at the center point for comparison. The addition of the center point to the experiment has no effect on the results of the regression, due to the zeros in the columns.

Table 24: 2^2 Experiment Results – 0YEY

Run #	MS Cost	PhD Cost	MS Quota	PhD Quota	Man-Years
1	0	0	15.84	3.49	34.22
2	1	1	15.80	3.51	53.54
3	1	-1	15.47	3.72	46.11
4	-1	1	15.96	3.43	21.72
5	-1	-1	15.96	3.43	14.85

First, just looking at the results, it can be seen that there is little effect noticed by changing the cost coefficients. This small change can best be viewed by looking at Figure 23. Figure 23 is a bar chart that compares MS quota and PhD quota at each of the experimental design points. Notice that the changes at each design setting are almost indiscernible.

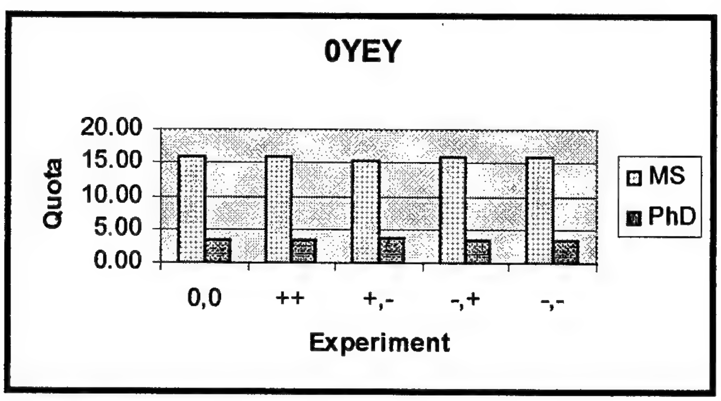


Figure 23: Bar Chart – 0YEY Cost Results

Next, look at the multiple-linear regression results for this 2^2 factorial experiment. Keeping in mind the results presented in Table 24 and Figure 23, it is

expected that MS cost and PhD cost will not be significant factors in determining quotas. However, costs will be significant to man-years determined because there is a direct relationship between the cost coefficients used in Equation (3-1) and the man-years determined by QuAM.

The ANOVA summary outputs for MS quota and man-years are seen in Figures 24 and 25. The ANOVA summary output for PhD quota is identical to the MS quota summary and is not shown. In Figure 24, note that 'Significance F' is 0.1814, meaning that this is not a significant model. A 'Significance F' value greater than 0.05 also signifies that each of the factor coefficients is approximately zero, and that only the intercept is significant to the model. This is also seen in the 'P-values'. Both the MS cost and the PhD cost 'P-values' are greater than 0.05, and therefore are not significant. In Figure 25, note the 'Significance F' is less than 0.05, denoting a significant model, and that both MS and PhD costs are significant factors (P-values less than 0.05) to man-year determination.

SUMMARY OUTPUT MS QUOTA					
Regression Statistics					
Multiple R	0.9047				
R Square	0.8186				
Adjusted R Square	0.6371				
Standard Error	0.1217				
Observations	5.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.1336	0.0668	4.5114	0.1814
Residual	2	0.0296	0.0148		
Total	4	0.1632			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	15.8062	0.0544	290.4471	0.0000	
MS Cost	-0.1623	0.0608	-2.6667	0.1165	
PhD Cost	0.0841	0.0608	1.3825	0.3009	

Figure 24: 0YEY ANOVA – MS Quota

SUMMARY OUTPUT MAN-YEARS					
Regression Statistics					
Multiple R	1.0000				
R Square	0.9999				
Adjusted R Square	0.9998				
Standard Error	0.2268				
Observations	5.0				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1046.0286	523.0143	10171.7558	0.0001
Residual	2	0.1028	0.0514		
Total	4	1046.1314			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	34.0888	0.1014	336.1541	0.0000	
MS Cost	15.7709	0.1134	139.1002	0.0001	
PhD Cost	3.5757	0.1134	31.5379	0.0010	

Figure 25: 0YEY ANOVA – Man-years

This portion of the research determined that the QuAM outputs of MS quota and PhD quota are not sensitive to changes in the cost coefficients. Of course man-years, the cost determined by QuAM, is sensitive to changes in the cost vector. A simple 2^2 factorial experiment was used along with multiple-linear regression to determine results. Recall, from Equation (3-1), that QuAM sums the number of personnel needed, without regard to military grade or longevity. The fact that just two costs are applied, regardless of military grade, in QuAM makes the results of this portion of the analysis fairly obvious. Future research may be needed to determine the effects of applying an individual cost to each military grade.

This chapter was centered on presenting the results of the QuAM analysis, using the methodology developed in previous chapters. The output of QuAM was compared with EDFLOW, its parent model, and determined to be mathematically identical. Sensitivity analysis was conducted using factorial experiments and multiple-linear regression to vary the LHS, RHS, and the cost coefficients. Input factors significant to QuAM's output were then determined. QuAM displayed simple

linear characteristics throughout the analysis, and performed without spikes or jumps regardless of the input factor values used.

QuAM is now transported to a spreadsheet environment and analyzed. The final chapter of this research provides recommendations for implementation and for further research. Concluding remarks are also provided.

CHAPTER V

RECOMMENDATIONS and CONCLUSION

INTRODUCTION

QuAM is now transported to an Excel spreadsheet environment, where it provides the same MS and PhD quotas as the FORTRAN 77 EDFLOW formulation. QuAM is a well-behaved, linear mathematical model. It has been tested for sensitivity to the input factors of attrition, requirement, and inventory factors, and has displayed simple linear tendencies with no large spikes or jumps at any input factor value settings.

This final chapter begins with a review of the basic assumptions behind the QuAM model. With those assumptions in mind, recommendations for model implementation are made. During the course of this research, areas requiring additional emphasis have been found, leading to recommendations for further research.

ASSUMPTIONS

Recall that QuAM is based on a Markov decision process. The assumptions basic to the QuAM model are driven by that process, and are summarized below. The key to each of these assumptions is that QuAM assumes a steady-state environment.

1. Personnel within an academic specialty are statistically identical and behave independently—QuAM determines quotas for academic specialties based on identically qualified individuals. The actions of one of those identical individuals has no affect on the rest, i.e., the attrition of one individual does not trigger a mass attrition in that identical group of individuals.

2. The average size and distribution of the overall population within a specialty remains constant—assumes an unchanging requirement for that specialty and that steady-state is maintained. This can be related to assumption one above, in that there are no large changes in numbers of personnel.
3. Future attrition probabilities are determined by current longevity and degree level—assumes that attrition is based solely on years of service and degree level. Currency of the degree is disregarded.
4. All graduate programs are completed successfully—assumes a 100 percent graduation rate, and that no attrition occurs during training.
5. Grade requirements can be satisfied only by educationally qualified personnel with appropriate longevity—assumes that lieutenant billets are filled by lieutenants, captain billets by captains, etc.
6. AFPC is 100 percent effective in assigning personnel with AADs to appropriate billets—assumes that personnel with required AADs are assigned to AAD billets. This assumption does not account for operational assignments or for professional military education.
7. Degrees are always valid once obtained—individuals with required degrees, remain part of the useable inventory until they are removed by attrition. Once again, this assumes that trained individuals are always available and assigned to their academic specialty, until leaving the system.
8. All model parameters are assumed to be constant—each of the input factor values (attrition, requirement, and inventory factors) are unchanged throughout the 23 years encompassed by the run of the model. Once again, the assumption of steady-state is present.

RECOMMENDATIONS

It is apparent from the assumptions above that QuAM actually determines a minimum quota allocation for each ASC. The quota allocation is a minimum due to the fact that QuAM assumes steady-state input parameters, perfect personnel management, and constant availability of personnel with required AADs to fill AAD billets. Recall from our findings in Chapter IV, that QuAM is dependent on accurate AAD requirement information and inventory factor values, but is not sensitive to changes in attrition.

QuAM as it stands now is an excellent personnel management tool. It provides the minimum annual quota allocation by grade that is required to maintain the steady-state requirements of a given ASC. QuAM, at its best, should be used by personnel managers to determine a minimum annual allocation of personnel for each ASC. That determined allocation should be educated by AFIT or AFIT-sponsored programs yearly. Educating this minimum quota should ensure that the AAD needs of the Air Force are continually met and that all available AAD personnel billets are able to be manned with qualified individuals.

The sensitivity analysis effort accomplished on QuAM has led to some areas that require additional research. They are:

1. QuAM is sensitive to the input requirements. Recall that the individual ASC requirements are maintained by the ASMs. The fact that AAD requirements are the driving factor in QuAM quota determination, and that requirements are assumed to be constant, emphasizes the necessity of an accurate requirement database. Specifically, research is needed to develop how requirements are determined and how they are maintained.
2. The inventory factors built into the model allow QuAM to provide an additional on-hand inventory of trained personnel. This additional inventory is necessary to allow personnel to attend professional military education, to be assigned to operational billets, and to provide an overlap of experienced personnel to enhance moves between billets. Research is needed to determine accurate inventory factor values to be used within QuAM. Accurate inventory factor values will allow personnel managers additional latitude by determining an annual allocation quota that will maintain a steady-state inventory of trained personnel above what is required by the baseline AAD requirement.
3. QuAM is currently not sensitive to changes in the costs to produce MS degrees and PhD degrees. The cost function in QuAM is based on man-years and treats all personnel, regardless of grade and longevity, identically. It is possible that man-years are not the only cost incurred by educating personnel. A relative cost by grade and/or longevity may be more useful to QuAM and its optimization processes. Additional research is needed to determine if a change to the cost function actually is significant to the annual quota allocations determined.

CONCLUSION

The QuAM model is a two-phase mathematical model based on a Markov decision process that is used to feed a linear optimization. Outputs from the model provide the minimum number of officers, by grade and academic specialty, which must be educated yearly to fill validated AAD billets. Inputs to the model include required AAD billets, by rank and degree level for each Air Force ASC, attrition rates, and inventory factor values. QuAM was originally coded in FORTRAN 77 and was designed to meet the specific objectives of an AFIT initiative.

This research effort focused on the QuAM model and the creation of a user-friendly tool. The model was transported from FORTRAN 77 to an Excel spreadsheet environment that uses a combination of Excel, VBA, and Excel Solver '97 to accomplish the data display, manipulation, and optimization. The majority of this research was centered on testing the model for sensitivity to variations in its five input factors. This sensitivity analysis was accomplished using a 2^5 factorial experiment and multiple-linear regression. Each of the input factors was tested for significance, using a 95 percent confidence level, against the model outputs of MS quota, PhD quota, and man-years.

The results of this research show that QuAM has been transported successfully to the user-friendly, point-and-click, environment of the Excel spreadsheet. The spreadsheet formulation matches the FORTRAN 77 formulation identically in each of the 26 ASCs tested. QuAM performs in a strictly linear manner without spikes or jumps. QuAM is sensitive to input AAD requirements, and to the

inventory factor values used. Surprisingly, QuAM is not sensitive to changes in attrition.

QuAM is ready to be used by personnel managers. It should be used to provide an annual minimum allocation of officers, by grade, that need to be trained by AFIT or AFIT-sponsored programs. QuAM is a tool waiting for use. Its use should help managers determine quotas that will continually meet the needs of the Air Force, now and in the future, in each of the academic specialties.

APPENDIX A: EDFLOW

Program EdFlow

```
c*****************************************************************c
c Determines annual minimum numbers of academic program entries   c
c needed to meet stable personnel requirements (given by degree   c
c level and grade) based on estimated attrition probabilities     c
c (given by degree level and longevity).                           c
c Calls IMSL subroutine DLPRS to solve a linear program.           c
c*****************************************************************c

      dimension A(200,200),B(200),C(200),IRTYPE(200),XLB(200),
     &  XUB(200),X(200),DSOL(200),Req(3,5),Att(22,3),Scale(3)

      character*4 Code,Query

      common /worksp/ rwksp
      real rwksp(27762)
      call iwkin(27762)

      open(11,file='edflow.dat',status='old')
      open(12,file='edflow.out',status='new')
      read(11,*) (Att(I,1),I=1,22)
      read(11,*) (Att(I,2),I=2,22)
      read(11,*) (Att(I,3),I=5,22)
      read(11,*) Scale(1)
      read(11,*) Scale(2)
      read(11,*) Scale(3)
      print*,'Enter Desired Ed Code (all=****):'
      read(*,5) Query
1     read(11,5) Code
5     format(A4)
      if (Code.ne.'DONE') then
          do 10 I=1,3
              read(11,*) (Req(I,J),J=1,5)
10          continue
          if (Req(3,1).ne.0.0) then
              Req(3,2)=Req(3,2)+Req(3,1)
              Req(3,1)=0.0
            endif
          if
(((Query(1:1).eq.'*').or.(Query(1:1).eq.Code(1:1))).and.
     &       ((Query(2:2).eq.'*').or.(Query(2:2).eq.Code(2:2))).and.
     &       ((Query(3:3).eq.'*').or.(Query(3:3).eq.Code(3:3))).and.
     &       ((Query(4:4).eq.'*').or.(Query(4:4).eq.Code(4:4)))) then
              do 20 I=1,200
                  B(I)=0.0
                  IRTYPE(I)=0
                  C(I)=0.0
                  X(I)=0.0
                  XLB(I)=0.0
```

```
                XUB(I)=-1.0E30
                DSOL(I)=0.0
                do 15 J=1,200
                    A(I,J)=0.0
15                continue
20            continue
            Cost=0.0
            M=139
            N=166
            A(2,1)=1.0
            do 25 I=2,23
                A(I+1,I)=1.0-Att(I-1,1)
                A(1,I)=Att(I-1,1)
25            continue
            A(1,24)=1.0
            do 30 I=25,46
                A(I+22,I)=1.0
30            continue
            do 35 I=47,67
                A(I+1,I)=1-Att(I-45,2)
                A(1,I)=Att(I-45,2)
35            continue
            A(1,68)=1
            do 40 I=69,106
                A(I+19,I)=1.0
40            continue
            do 45 I=107,124
                A(I+1,I)=1-Att(I-102,3)
                A(1,I)=Att(I-102,3)
45            continue
            A(1,125)=1.0
            do 50 I=126,147
                A(I-101,I)=1.0
50            continue
            do 55 I=148,166
                A(I-79,I)=1.0
55            continue
            do 60 I=1,125
                A(I,I)=-1.0
60            continue
            do 65 I=1,22
                A(I,I+125)=-1.0
65            continue
            do 70 I=47,65
                A(I,I+101)=-1.0
70            continue
            do 95 I=1,3
                do 90 J=1,5
                    do 85 K=I,3
                        B(124+(I-1)*5+J)=
     &                      B(124+(I-1)*5+J)+Req(K,J)*Scale(K)
85                  continue
90                continue
95            continue
            do 100 I=125,M
```

```
            IRTYPE(I)=2
100       continue
        do 105 I=1,200
            A(125,I)=0.0
105       continue

        call PutOne(125,1,4,A)
        call PutOne(125,47,48,A)

        call PutOne(126,5,11,A)
        call PutOne(126,49,55,A)
        call PutOne(126,107,112,A)

        call PutOne(127,12,16,A)
        call PutOne(127,56,60,A)
        call PutOne(127,113,117,A)

        call PutOne(128,17,20,A)
        call PutOne(128,61,64,A)
        call PutOne(128,118,121,A)

        call PutOne(129,21,24,A)
        call PutOne(129,65,68,A)
        call PutOne(129,122,125,A)

        call PutOne(130,47,48,A)

        call PutOne(131,49,55,A)
        call PutOne(131,107,112,A)

        call PutOne(132,56,60,A)
        call PutOne(132,113,117,A)

        call PutOne(133,61,64,A)
        call PutOne(133,118,121,A)

        call PutOne(134,65,68,A)
        call PutOne(134,122,125,A)

        call PutOne(136,107,112,A)
        call PutOne(137,113,117,A)
        call PutOne(138,118,121,A)
        call PutOne(139,122,125,A)

        do 110 I=25,46
            C(I)=1.0
110       continue
        do 115 I=69,87
            C(I)=2.0
115       continue
        call DLPRS(M,N,A,200,B,B,C,IRTYPE,XLB,XUB,Cost,X,DSOL)
        write(12,120) Code
120     format('1',//////' REQUIREMENTS:   ',A4)
        write(12,125)
125     format(/1X,'        LT     CPT     MAJ     LTC     COL')
```

```
            write(12,130) ' BS ', (Req(1,J),J=1,5), SumR(1,Req)
            write(12,130) ' MS ', (Req(2,J),J=1,5), SumR(2,Req)
            write(12,130) ' PHD', (Req(3,J),J=1,5), SumR(3,Req)
130         format(A4,5F7.1,F11.1,4F7.1,F11.1)
          write(12,135)
135         format(/' INVENTORY FACTOR')
            write(12,*)
            write(12,130) ' BS ', Scale(1)
            write(12,130) ' MS ', Scale(2)
            write(12,130) ' PHD', Scale(3)
            write(12,140)
140         format(/' ATTRITION')
            write(12,*)
            write(12,145) (I,I=1,22)
145         format(6X,22I5)
            write(12,147) (Att(I,1),I=1,22)
147         format(6X,22F5.2,'        BS')
            write(12,148) (Att(I,2),I=2,22)
148         format(11X,21F5.2,'       MS')
            write(12,150) (Att(I,3),I=5,22)
150         format(26X,18F5.2,'       PHD')
            write(12,155)
155         format(//' PRIMAL SOLUTION')
            write(12,160)
160
format(/4X,'LT',17X,'CPT',32X,'MAJ',22X,'LTC',17X,'COL')
            write(12,205) (I,I=0,23)
205         format(1X,24I5)
            write(12,*)
            write(12,210) (X(I)+X(I+125),I=1,22),X(23),X(24)
210         format(1X,24F5.1,'  BS')
            write(12,*)
            write(12,215) (X(I),I=25,46)
215         format(6X,22F5.1)
            write(12,*)
            write(12,220) (X(I)+X(I+101),I=47,65),(X(I),I=66,68)
220         format(11X,22F5.1,'  MS')
            write(12,*)
            write(12,225) (X(I),I=69,87)
225         format(16X,19F5.1)
            write(12,*)
            write(12,230) (X(I),I=88,106)
230         format(21X,19F5.1)
            write(12,*)
            write(12,235) (X(I),I=107,125)
235         format(26X,19F5.1,'  PHD')
            write(12,*)
            write(12,237) SumX(126,147,X)
237         format(' Annual MS (m):  ',F5.1)
            write(12,238) SumX(148,166,X)
238         format(' Annual PHD (p): ',F5.1)
            write(12,240) Cost
240         format(' Cost (m+2p):    ',F5.1)
            write(12,245)
```

```
245             format(//' DUAL SOLUTION',34X,'STEADY-STATE
INVENTORY')
                write(12,247)
247             format(/1X,'          LT     CPT     MAJ     LTC      COL',
     &            7X,'      LT     CPT     MAJ     LTC     COL')
                write(12,248) ' BS ', (DSOL(I),I=125,129),
     &            SumX(1,4,X),SumX(5,11,X),SumX(12,16,X),
     &              SumX(17,20,X),SumX(21,24,X),SumX(1,24,X)
                write(12,248) ' MS ', (DSOL(I),I=130,134),
     &            SumX(47,48,X),SumX(49,55,X),SumX(56,60,X),
     &              SumX(61,64,X),SumX(65,68,X),SumX(47,68,X)
                write(12,248) ' PHD', (DSOL(I),I=135,139),
     &            0.0,SumX(107,112,X),SumX(113,117,X),
     &              SumX(118,121,X),SumX(122,125,X),SumX(107,125,X)
248             format(A4,5F7.2,F14.1,4F7.1,4F11.1)
                write(12,249)
249             format(//' THIS SOLUTION STRICTLY ENFORCES GRADE'
     &            ,' REQUIREMENTS')
                write(*,250) Code
250             format(' Done with ',A4)
              endif
            goto 1
          endif
        close(11)
        close(12)
        end

C*******************************************************************

        subroutine PutOne(I,J,K,A)
        dimension A(200,200)
        do 300 L=J,K
            A(I,L)=1.0
300       continue
        return
        end

        function SumX(I,J,X)
        dimension X(200)
        SumX=0.0
        do 305 K=I,J
            SumX=SumX+X(K)
305       continue
        return
        end

        function SumR(I,Req)
        dimension Req(3,5)
        SumR=0
        do 310 J=1,5
            SumR=SumR+Req(I,J)
310       continue
        return
        end
```

APPENDIX B: QuAM

Instructions Worksheet

WELCOME TO THE QUOTA ALLOCATION SPREADSHEET MODEL.

The solutions developed by this model strictly enforce grade requirements.

There are only five factors, which should be updated on the Master Worksheet.

1. Attrition Factor: This factor was built into the model as a means to vary attrition, without changing the baseline attrition data.

    Attrition factor will normally be set to 1.0

    Baseline attrition data can be changed only on the Attrition Worksheet.

2. Requirements Factor: This factor was built into the model as a means to vary the requirements without changing the baseline requirements.

    Requirements factor will normally be set to 1.0

    Baseline requirement data can be changed only on the Requirements Worksheet.

3. Inventory Factors (3): These factors are used to maintain an inventory of personnel above the baseline requirement.

    a. BS--Inventory Factor for BS Degrees. Will normally be set to 1.0, but can be set to any value because there is no BS requirement.

    b. MS--Inventory Factor for MS Degrees. ***Normal values -- 1.0 to 1.5***

    c. PhD--Inventory Factor for PhD Degrees. ***Normal values --1.0 to 1.5***

After updating Factors to required values, click the run button. The program will automatically load the requirements for each of the ASCs
and solve for the annual optimal number of MS and PhD quotas by grade.
Requires approximately 20 seconds per ASC

To view the formulation of an individual solution, you will need to Run the MACRO for that ASC.

There is a MACRO for each of the ASCs. The MACROs are listed by name rather than 4 digit code due to VBA constraints.

Once the solution is reached, select the Individual Tab to view the formulation and solution.

Master Worksheet (Partial)

Quota Allocation Model: This Solution Strictly Enforces Grade Requirements.

***** THIS IS THE ONLY COLOR CELL THAT CAN BE CHANGED IN THIS WORKBOOK*****

Attrition Factor:	1.00	***Only These Five Cells Should Be Updated on this Worksheet***				
Requirements Factor:		1.00				
Inventory Factors:	BS:	1.00	MS:	1.00	PhD:	1.00

***** AFTER UPDATING THE APPROPRIATE CELLS, SELECT THE RUN MACRO FOR ALL*****
*****TO SEE AN INDIVIDUAL ED CODE, UPDATE THE APPROPRIATE CELLS, SELECT THE INDIVIDUAL MACRO*****

Varied by solver.	Determined by formula.	Used to change parameters

4Axx	Aeronautical Engineering					
Optimum:	per year!	Optimal Graduating Class Structure				
MS:	25.2	25.2	0.0	0.0	0.0	0.0
PhD:	6.2	0.0	6.2	0.0	0.0	0.0
Manyears:	56.5	Lt	Capt	Maj	Lt Col	Col

4Bxx	Aerospace Engineering					
Optimum:	per year!	Optimal Graduating Class Structure				
MS:	2.1	1.0	0.8	0.3	0.0	0.0
PhD	0.5	0.0	0.5	0.0	0.0	0.0
Manyears	4.7	Lt	Capt	Maj	Lt Col	Col

4Exx	Astronautical Engineering					
Optimum:	per year!	Optimal Graduating Class Structure				
MS:	9.8	9.8	0.0	0.0	0.0	0.0
PhD:	1.3	0.0	1.3	0.0	0.0	0.0
Manyears:	18.8	Lt	Capt	Maj	Lt Col	Col

4Ixx	Electrical Engineering					
Optimum:	per year!	Optimal Graduating Class Structure				
MS:	62.4	62.4	0.0	0.0	0.0	0.0
PhD:	10.4	0.0	10.4	0.0	0.0	0.0
Manyears:	125.0	Lt	Capt	Maj	Lt Col	Col

4Mxx	Mechanical Engineering					
Optimum:	per year!	Optimal Graduating Class Structure				
MS:	11.5	11.5	0.0	0.0	0.0	0.0
PhD:	2.5	0.0	2.5	0.0	0.0	0.0
Manyears:	24.9	Lt	Capt	Maj	Lt Col	Col

4Qxx	Nuclear Engineering					
Optimum:	per year!	Optimal Graduating Class Structure				
MS:	4.8	2.0	2.3	0.0	0.5	0.0
PhD:	1.0	0.0	1.0	0.0	0.0	0.0
Manyears:	10.2	Lt	Capt	Maj	Lt Col	Col

4Txx	Systems Engineering					
Optimum:	per year!	Optimal Graduating Class Structure				
MS:	5.6	3.7	1.9	0.0	0.0	0.0
PhD:	0.3	0.0	0.2	0.1	0.0	0.0
Manyears:	9.2	Lt	Capt	Maj	Lt Col	Col

Formulation Worksheet (Partial)

Quota Allocation Model: This Solution Strictly Enforces Grade Requirements.

Optimum: per year!		Optimal Graduating Class Structure				
MS:	62.44	62.44	0.00	0.00	0.00	0.00
PhD:	10.44	0.00	10.44	0.00	0.00	0.00
Manyears:	124.99	**Lt**	**Capt**	**Maj**	**Lt Col**	**Col**

***** THIS WORKSHEET IS USED IN CONJUNCTION WITH THE MASTER PROGRAM*****

***** THERE ARE NO CELLS THAT CAN BE CHANGED IN THIS WORKSHEET*****

Attrition Factor:		**1.00**				
Requirements Factor:			**1.00**			
Inventory Factors:	**BS:**		**1.00**	**MS:**	**1.00**	**PhD:**	**1.00**

Variables:

x -- number of officers with i years of service and k years of graduate education (no action taken)
x' -- number of officers with i years of service and k years of graduate education (sent to school)

Parameters:

Attrition (a) -- attrition probability for officers with i years of service and degree level d (a ranges from 0 to 1).

Requirements (R) -- requirement (number of authorized positions) for officers with degree level d and grade g.

Inventory Factor (f) -- inventory factor for degree level d (desired ratio of inventory to authorized positions).

This is the LP formulation area:

	0	**BS**
d =	1	**MS**
	2	**PhD**

	2	**Lt**
	3	**Capt**
g =	4	**Maj**
	5	**Lt Col**
	6	**Col**

i = 0...23

	0
	1
	2
k =	3
	4
	5

Varied by solver. **Determined by formula.** **Used to change parameters**

g =			**2**					**3**			
i =	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
x (0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
x' (0)	62.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
x (1)		62.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
x (2)			52.0	52.0	51.4	50.5	49.2	47.1	45.2	42.3	40.1
x' (2)			10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
x (3)				10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
x (4)					10.4	0.0	0.0	0.0	0.0	0.0	0.0
x (5)						10.4	10.4	10.4	10.4	10.4	9.8
Attrition:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
a (0)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
a (1)			0.00	0.01	0.02	0.03	0.04	0.04	0.06	0.05	0.05
a (2)	**Factor:**	**1.00**				0.00	0.00	0.00	0.00	0.06	0.02

Requirements (4lxx):

	Lt	**Capt**	**Maj**	**Lt Col**	**Col**	**Total**
R (0)	0.00	0.00	0.00	0.00	0.00	0.00
R (1)	92.00	291.00	67.00	18.00	9.00	477.00
R (2)	12.00	50.00	32.00	17.00	2.00	113.00
Factor:	**1.00**				**Total**	**590.00**

Inventory factor:

f (0)	**1.0**
f (1)	**1.0**
f (2)	**1.0**

Work area for constraints:

	Grade:	**Sums:**	**R * f**	**Sumproducts:**	
BS	**2**	104.0	104	**0**	0.0
	3	387.9	341	**2**	41.5
	4	217.5	99	**5**	7.6
	5	142.9	35	**Total:**	62.4
	6	87.1	11		
	2	104.0	104		
	3	387.9	341		

Cross-Check MS requirements!

Years	**Constraints:**	**x (0)**
0	62.4	62.4
1	0.0	0.0
2	0.0	0.0
3	0.0	0.0
4	0.0	0.0
5	0.0	0.0
6	0.0	0.0

APPENDIX C: VISUAL BASIC for APPLICATIONS CODE

```
Sub Run()
' Run Macro
'This MACRO will evaluate each of the ASCs and update the
'information on the master worksheet.
        Dim i As Integer
        i = 93
        Sheets("Worksheet").Select
        Range("C12").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("D13").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("D14").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("F14").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("H14").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        While i <= 243
        Sheets("Worksheet").Select
        Cells(51, 1) = Cells(i - 2, 8)
        Cells(53, 2) = Cells(i, 9)
        Cells(54, 2) = Cells(i + 1, 9)
        Cells(55, 2) = Cells(i + 2, 9)
        Cells(53, 3) = Cells(i, 10)
        Cells(54, 3) = Cells(i + 1, 10)
        Cells(55, 3) = Cells(i + 2, 10)
        Cells(53, 4) = Cells(i, 11)
        Cells(54, 4) = Cells(i + 1, 11)
        Cells(55, 4) = Cells(i + 2, 11)
        Cells(53, 5) = Cells(i, 12)
        Cells(54, 5) = Cells(i + 1, 12)
        Cells(55, 5) = Cells(i + 2, 12)
        Cells(53, 6) = Cells(i, 13)
        Cells(54, 6) = Cells(i + 1, 13)
        Cells(55, 6) = Cells(i + 2, 13)
        Range("G56").Select
        Application.Run "QModel2.xls!Solver"
        Cells(i, 2) = Cells(4, 2)
        Cells(i + 1, 2) = Cells(5, 2)
        Cells(i + 2, 2) = Cells(6, 2)
        Cells(i, 3) = Cells(4, 3)
```

```
        Cells(i + 1, 3) = Cells(5, 3)
        Cells(i, 4) = Cells(4, 4)
        Cells(i + 1, 4) = Cells(5, 4)
        Cells(i, 5) = Cells(4, 5)
        Cells(i + 1, 5) = Cells(5, 5)
        Cells(i, 6) = Cells(4, 6)
        Cells(i + 1, 6) = Cells(5, 6)
        Cells(i, 7) = Cells(4, 7)
        Cells(i + 1, 7) = Cells(5, 7)
        i = i + 6
        Wend
        Sheets("Master").Select
        Cells(13, 1).Select
End Sub

Sub Solver()
' Solver Macro
'This MACRO calls the Solver and accepts the values.
    SolverOk SetCell:="$B$6", MaxMinVal:=2, ValueOf:="0", ByChange:= _
    "$B$39:$Y$39,$B$40:$W$40,$C$41:$X$41,$D$42:$Y$42,$D$43:$V$43,$E
    $44:$W$44,$F$45:$X$45,$G$46:$Y$46"
    SolverSolve UserFinish:=True
End Sub

Sub ElectricalEng()
    ' ElectricalEng Macro
    'This MACRO will evaluate the 4Ixx ASC.
        Sheets("Individual").Select
        Range("C12").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("D13").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("D14").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("F14").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("H14").Select
        ActiveCell.FormulaR1C1 = "=Master!R[-8]C"
        Range("A51").Select
        ActiveCell.FormulaR1C1 = "=Requirements!R[-21]C"
        Range("B53").Select
        ActiveCell.FormulaR1C1 = "=PRODUCT(R56C2,Requirements!R[-21]C)"
        Range("B53").Select
        Selection.AutoFill Destination:=Range("B53:B55"), Type:=xlFillDefault
        Range("B53:B55").Select
```

```
        Range("B53").Select
        Selection.AutoFill Destination:=Range("B53:F53"), Type:=xlFillDefault
        Range("B53:F53").Select
        Range("B54").Select
        Selection.AutoFill Destination:=Range("B54:F54"), Type:=xlFillDefault
        Range("B54:F54").Select
        Range("B55").Select
        Selection.AutoFill Destination:=Range("B55:F55"), Type:=xlFillDefault
        Range("B55:F55").Select
        Range("G56").Select
        Application.Run "QModel2.xls!Solver"
        Sheets("Master").Select
        Cells(31, 1).Select
End Sub

Sub Experiment()
'This MACRO runs the full factorial experiment on whatever
'individual worksheet that is called.  The individual ASC
'must first be run.
        Dim i As Integer
        i = 95
        Sheets("Individual").Select
        While i <= 126
          Cells(12, 3) = Cells(i, 10)
          Cells(13, 4) = Cells(i, 11)
          Cells(14, 4) = Cells(i, 12)
          Cells(14, 6) = Cells(i, 13)
          Cells(14, 8) = Cells(i, 14)
          Cells(56, 7).Select
          Application.Run "'QModel2.xls'!Solver"
          Cells(i, 15) = Cells(4, 2)
          Cells(i, 16) = Cells(5, 2)
          Cells(i, 17) = Cells(6, 2)
          Cells(i, 6) = Cells(i, 15)
          Cells(i, 7) = Cells(i, 16)
          Cells(i, 8) = Cells(i, 17)
          i = i + 1
          Wend
          Cells(126, 8).Select
End Sub
```

APPENDIX D: SENSITIVITY ANALYSIS RESULTS

INPUT PARAMETERS

1 Denotes Significant

BS	0	0	0	0	0	0	0	0	0	0	0	0	0
MS	4	37	60	68	93	77	118	70	66	118	20	80	19
PhD	0	0	0	0	0	1	2	2	2	4	1	4	1
Total	4	37	60	68	93	78	120	72	68	122	21	84	20
Ratio	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.03	0.03	0.05	0.05	0.05
M-Y	1AMM	1AMJ	0YRY	1AMH	1AUY	1ATY	1ASY	0YSY	4Txx	1AMY	1AMS	1ASA	1ASM
a	1	1	1	1	1	1	1	1	1	1	1	1	1
R	1	1	1	1	1	1	1	1	1	1	1	1	1
f0	0	0	0	0	0	0	0	0	0	0	0	0	0
f1	1	1	1	1	1	1	1	1	1	1	1	1	1
f2	0	0	0	0	0	1	1	1	1	1	1	1	1
MS	1AMM	1AMJ	0YRY	1AMH	1AUY	1ATY	1ASY	0YSY	4Txx	1AMY	1AMS	1ASA	1ASM
a	1	1	1	1	1	1	1	1	1	1	1	1	1
R	1	1	1	1	1	1	1	1	1	1	1	1	1
f0	0	0	0	0	0	0	0	0	0	0	0	0	0
f1	1	1	1	1	1	1	1	1	1	1	1	1	1
f2	0	0	0	0	0	0	0	0	0	0	0	0	0
PhD	1AMM	1AMJ	0YRY	1AMH	1AUY	1ATY	1ASY	0YSY	4Txx	1AMY	1AMS	1ASA	1ASM
a	0	0	0	0	0	1	1	1	1	1	0	1	1
R	0	0	0	0	0	1	1	1	1	1	1	1	1
f0	0	0	0	0	0	0	0	0	0	0	0	0	0
f1	0	0	0	0	0	0	0	0	0	0	0	0	0
f2	0	0	0	0	0	1	1	1	1	1	1	1	1

Figure 26: Parameter Analysis (Part 1)

BS	0	0	0	0	0	0	0	0	0	0	0	0	0
MS	146	244	286	28	80	155	477	44	19	45	60	131	109
PhD	8	20	28	4	16	35	113	11	5	12	21	60	76
Total	154	264	314	32	96	190	590	55	24	57	81	191	185
Ratio	0.05	0.08	0.10	0.14	0.20	0.23	0.24	0.25	0.26	0.27	0.35	0.46	0.70
M-Y	1AGE	8Fxx	0Cxx	1APY	4Exx	0YEY	4Ixx	4Wxx	4Bxx	4Qxx	4Mxx	4Axx	8Hxx
a	1	1	1	1	0	1	0	0	1	1	0	0	0
R	1	1	1	1	1	1	1	1	1	1	1	1	1
f0	0	0	0	0	0	0	0	0	0	0	0	0	0
f1	1	1	1	1	1	1	1	1	1	1	1	1	1
f2	1	1	1	1	1	1	1	1	1	1	1	1	1
MS	1AGE	8Fxx	0Cxx	1APY	4Exx	0YEY	4Ixx	4Wxx	4Bxx	4Qxx	4Mxx	4Axx	8Hxx
a	1	1	1	1	0	1	0	0	1	1	0	0	0
R	1	1	1	1	1	1	1	1	1	1	1	1	1
f0	0	0	0	0	0	0	0	0	0	0	0	0	0
f1	1	1	1	1	1	1	1	1	1	1	1	1	1
f2	1	1	1	1	1	1	1	1	1	1	1	1	1
PhD	1AGE	8Fxx	0Cxx	1APY	4Exx	0YEY	4Ixx	4Wxx	4Bxx	4Qxx	4Mxx	4Axx	8Hxx
a	0	1	0	1	0	1	0	0	0	0	0	0	0
R	1	1	1	1	1	1	1	1	1	1	1	1	1
f0	0	0	0	0	0	0	0	0	0	0	0	0	0
f1	0	0	0	0	0	0	0	0	0	0	0	0	0
f2	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 27: Parameter Analysis (Part 2)

0YEY

This is the Full-Factorial experiment for the 0YEY Ed Code.

a	R	f0	f1	f2	MS	PhD	Manyears
-1.00	-1.00	-1.00	-1.00	-1.00	13.74	3.08	29.86
-1.00	-1.00	-1.00	-1.00	1.00	15.19	4.64	36.70
-1.00	-1.00	-1.00	1.00	-1.00	19.17	3.07	37.95
-1.00	-1.00	-1.00	1.00	1.00	20.61	4.62	44.79
-1.00	-1.00	1.00	-1.00	-1.00	13.74	3.08	29.86
-1.00	-1.00	1.00	-1.00	1.00	15.19	4.64	36.70
-1.00	-1.00	1.00	1.00	-1.00	19.17	3.07	37.95
-1.00	-1.00	1.00	1.00	1.00	20.61	4.62	44.79
-1.00	1.00	-1.00	-1.00	-1.00	16.80	3.77	36.50
-1.00	1.00	-1.00	-1.00	1.00	18.56	5.67	44.86
-1.00	1.00	-1.00	1.00	-1.00	23.43	3.75	46.39
-1.00	1.00	-1.00	1.00	1.00	25.19	5.65	54.75
-1.00	1.00	1.00	-1.00	-1.00	16.80	3.77	36.50
-1.00	1.00	1.00	-1.00	1.00	18.56	5.67	44.86
-1.00	1.00	1.00	1.00	-1.00	23.43	3.75	46.39
-1.00	1.00	1.00	1.00	1.00	25.19	5.65	54.75
1.00	-1.00	-1.00	-1.00	-1.00	14.76	3.20	31.74
1.00	-1.00	-1.00	-1.00	1.00	16.22	4.81	38.75
1.00	-1.00	-1.00	1.00	-1.00	20.68	3.19	40.60
1.00	-1.00	-1.00	1.00	1.00	22.14	4.80	47.61
1.00	-1.00	1.00	-1.00	-1.00	14.76	3.20	31.74
1.00	-1.00	1.00	-1.00	1.00	16.22	4.81	38.75
1.00	-1.00	1.00	1.00	-1.00	20.68	3.19	40.60
1.00	-1.00	1.00	1.00	1.00	22.14	4.80	47.61
1.00	1.00	-1.00	-1.00	-1.00	18.04	3.91	38.79
1.00	1.00	-1.00	-1.00	1.00	19.83	5.87	47.36
1.00	1.00	-1.00	1.00	-1.00	25.27	3.90	49.62
1.00	1.00	-1.00	1.00	1.00	27.06	5.87	58.19
1.00	1.00	1.00	-1.00	-1.00	18.04	3.91	38.79
1.00	1.00	1.00	-1.00	1.00	19.83	5.87	47.36
1.00	1.00	1.00	1.00	-1.00	25.27	3.90	49.62
1.00	1.00	1.00	1.00	1.00	27.06	5.87	58.19

Figure 28: 0YEY Factorial Experiment

SUMMARY OUTPUT MAN-YEARS					
Regression Statistics					
Multiple R	0.9962				
R Square	0.9924				
Adjusted R Square	0.9913				
Standard Error	0.7181				
Observations	32.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	1823.0419	455.7605	883.8734	0.0000
Residual	27	13.9223	0.5156		
Total	31	1836.9642			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	42.7789	0.1269	337.0014	0.0000	
a	1.3027	0.1269	10.2626	0.0000	
R	4.2779	0.1269	33.7001	0.0000	
f1	4.7091	0.1269	37.0969	0.0000	
f2	3.8467	0.1269	30.3034	0.0000	
SUMMARY OUTPUT MS QUOTA					
Regression Statistics					
Multiple R	0.9957				
R Square	0.9914				
Adjusted R Square	0.9902				
Standard Error	0.3920				
Observations	32.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	480.0478	120.0119	781.0866	0.0000
Residual	27	4.1485	0.1536		
Total	31	484.1963			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	19.7933	0.0693	285.6481	0.0000	
a	0.7064	0.0693	10.1947	0.0000	
R	1.9793	0.0693	28.5648	0.0000	
f1	3.1518	0.0693	45.4848	0.0000	
f2	0.8069	0.0693	11.6449	0.0000	
SUMMARY OUTPUT PHD QUOTA					
Regression Statistics					
Multiple R	0.9959				
R Square	0.9918				
Adjusted R Square	0.9909				
Standard Error	0.0957				
Observations	32.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	31.0139	10.3380	1129.2465	0.0000
Residual	28	0.2563	0.0092		
Total	31	31.2703			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	4.3630	0.0169	257.9494	0.0000	
a	0.0810	0.0169	4.7910	0.0000	
R	0.4363	0.0169	25.7949	0.0000	
f2	0.8788	0.0169	51.9558	0.0000	

Figure 29: 0YEY Summary Output / ANOVA

1AGE

This is the Full-Factorial experiment for the 1AGE Ed Code.

a	R	f0	f1	f2	MS	PhD	Manyears
-1.00	-1.00	-1.00	-1.00	-1.00	14.89	0.76	24.61
-1.00	-1.00	-1.00	-1.00	1.00	15.27	1.14	26.31
-1.00	-1.00	-1.00	1.00	-1.00	21.96	0.76	35.21
-1.00	-1.00	-1.00	1.00	1.00	22.34	1.14	36.91
-1.00	-1.00	1.00	-1.00	-1.00	14.89	0.76	24.61
-1.00	-1.00	1.00	-1.00	1.00	15.27	1.14	26.31
-1.00	-1.00	1.00	1.00	-1.00	21.96	0.76	35.21
-1.00	-1.00	1.00	1.00	1.00	22.34	1.14	36.91
-1.00	1.00	-1.00	-1.00	-1.00	18.20	0.93	30.08
-1.00	1.00	-1.00	-1.00	1.00	18.66	1.39	32.16
-1.00	1.00	-1.00	1.00	-1.00	26.84	0.93	43.03
-1.00	1.00	-1.00	1.00	1.00	27.30	1.39	45.12
-1.00	1.00	1.00	-1.00	-1.00	18.20	0.93	30.08
-1.00	1.00	1.00	-1.00	1.00	18.66	1.39	32.16
-1.00	1.00	1.00	1.00	-1.00	26.84	0.93	43.03
-1.00	1.00	1.00	1.00	1.00	27.30	1.39	45.12
1.00	-1.00	-1.00	-1.00	-1.00	15.19	0.76	25.06
1.00	-1.00	-1.00	-1.00	1.00	15.57	1.14	26.76
1.00	-1.00	-1.00	1.00	-1.00	22.40	0.76	35.88
1.00	-1.00	-1.00	1.00	1.00	22.78	1.14	37.58
1.00	-1.00	1.00	-1.00	-1.00	15.19	0.76	25.06
1.00	-1.00	1.00	-1.00	1.00	15.57	1.14	26.76
1.00	-1.00	1.00	1.00	-1.00	22.40	0.76	35.88
1.00	-1.00	1.00	1.00	1.00	22.78	1.14	37.58
1.00	1.00	-1.00	-1.00	-1.00	18.56	0.93	30.62
1.00	1.00	-1.00	-1.00	1.00	19.03	1.39	32.71
1.00	1.00	-1.00	1.00	-1.00	27.38	0.93	43.85
1.00	1.00	-1.00	1.00	1.00	27.84	1.39	45.94
1.00	1.00	1.00	-1.00	-1.00	18.56	0.93	30.62
1.00	1.00	1.00	-1.00	1.00	19.03	1.39	32.71
1.00	1.00	1.00	1.00	-1.00	27.38	0.93	43.85
1.00	1.00	1.00	1.00	1.00	27.84	1.39	45.94

Figure 30: 1AGE Factorial Experiment

SUMMARY OUTPUT MAN-YEARS

Regression Statistics	
Multiple R	0.9962
R Square	0.9924
Adjusted R Square	0.9913
Standard Error	0.6602
Observations	32.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	1545.5589	386.3897	886.3652	0.0000
Residual	27	11.7700	0.4359		
Total	31	1557.3290			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	34.4894	0.1167	295.4981	0.0000
a	0.3107	0.1167	2.6619	0.0129
R	3.4489	0.1167	29.5498	0.0000
f1	5.9506	0.1167	50.9834	0.0000
f2	0.9473	0.1167	8.1162	0.0000

SUMMARY OUTPUT MS QUOTA

Regression Statistics	
Multiple R	0.9961
R Square	0.9921
Adjusted R Square	0.9910
Standard Error	0.4354
Observations	32.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	645.9824	161.4956	852.0751	0.0000
Residual	27	5.1174	0.1895		
Total	31	651.0997			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	20.8879	0.0770	271.4112	0.0000
a	0.2049	0.0770	2.6628	0.0129
R	2.0888	0.0770	27.1411	0.0000
f1	3.9671	0.0770	51.5469	0.0000
f2	0.2105	0.0770	2.7353	0.0109

SUMMARY OUTPUT PHD QUOTA

Regression Statistics	
Multiple R	0.9960
R Square	0.9920
Adjusted R Square	0.9915
Standard Error	0.0221
Observations	32.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1.7726	0.8863	1807.3259	0.0000
Residual	29	0.0142	0.0005		
Total	31	1.7868			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.0525	0.0039	268.8736	0.0000
R	0.1053	0.0039	26.8874	0.0000
f2	0.2105	0.0039	53.7747	0.0000

Figure 31: 1AGE Summary Output / ANOVA

4Ixx

This is the Full-Factorial experiment for the 4Ixx Ed Code.

a	R	f0	f1	f2	MS	PhD	Manyears
-1.00	-1.00	-1.00	-1.00	-1.00	56.19	9.39	112.44
-1.00	-1.00	-1.00	-1.00	1.00	63.58	14.08	137.61
-1.00	-1.00	-1.00	1.00	-1.00	76.89	9.39	143.49
-1.00	-1.00	-1.00	1.00	1.00	84.28	14.08	168.66
-1.00	-1.00	1.00	-1.00	-1.00	56.19	9.39	112.44
-1.00	-1.00	1.00	-1.00	1.00	63.58	14.08	137.61
-1.00	-1.00	1.00	1.00	-1.00	76.89	9.39	143.49
-1.00	-1.00	1.00	1.00	1.00	84.28	14.08	168.66
-1.00	1.00	-1.00	-1.00	-1.00	68.67	11.47	137.43
-1.00	1.00	-1.00	-1.00	1.00	77.71	17.21	168.20
-1.00	1.00	-1.00	1.00	-1.00	93.97	11.47	175.38
-1.00	1.00	-1.00	1.00	1.00	103.01	17.21	206.15
-1.00	1.00	1.00	-1.00	-1.00	68.67	11.47	137.43
-1.00	1.00	1.00	-1.00	1.00	77.71	17.21	168.20
-1.00	1.00	1.00	1.00	-1.00	93.97	11.47	175.38
-1.00	1.00	1.00	1.00	1.00	103.01	17.21	206.15
1.00	-1.00	-1.00	-1.00	-1.00	56.21	9.41	112.53
1.00	-1.00	-1.00	-1.00	1.00	63.61	14.11	137.75
1.00	-1.00	-1.00	1.00	-1.00	76.91	9.41	143.58
1.00	-1.00	-1.00	1.00	1.00	84.31	14.11	168.80
1.00	-1.00	1.00	-1.00	-1.00	56.21	9.41	112.53
1.00	-1.00	1.00	-1.00	1.00	63.61	14.11	137.75
1.00	-1.00	1.00	1.00	-1.00	76.91	9.41	143.58
1.00	-1.00	1.00	1.00	1.00	84.31	14.11	168.80
1.00	1.00	-1.00	-1.00	-1.00	68.70	11.50	137.54
1.00	1.00	-1.00	-1.00	1.00	77.75	17.25	168.36
1.00	1.00	-1.00	1.00	-1.00	94.00	11.50	175.49
1.00	1.00	-1.00	1.00	1.00	103.05	17.25	206.31
1.00	1.00	1.00	-1.00	-1.00	68.70	11.50	137.54
1.00	1.00	1.00	-1.00	1.00	77.75	17.25	168.36
1.00	1.00	1.00	1.00	-1.00	94.00	11.50	175.49
1.00	1.00	1.00	1.00	1.00	103.05	17.25	206.31

Figure 32: 4Ixx Factorial Experiment

SUMMARY OUTPUT MAN-YEARS					
Regression Statistics					
Multiple R	0.9967				
R Square	0.9934				
Adjusted R Square	0.9926				
Standard Error	2.3754				
Observations	32.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	23602.1228	7867.3743	1394.2450	0.0000
Residual	28	157.9970	5.6427		
Total	31	23760.1198			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	156.2321	0.4199	372.0487	0.0000	
R	15.6235	0.4199	37.2056	0.0000	
f1	17.2500	0.4199	41.0788	0.0000	
f2	13.9968	0.4199	33.3318	0.0000	

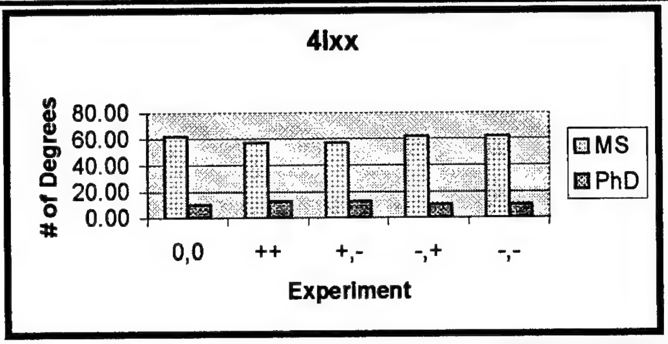
SUMMARY OUTPUT MS QUOTA					
Regression Statistics					
Multiple R	0.9965				
R Square	0.9929				
Adjusted R Square	0.9922				
Standard Error	1.3057				
Observations	32.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	6722.0258	2240.6753	1314.2437	0.0000
Residual	28	47.7377	1.7049		
Total	31	6769.7635			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	78.0519	0.2308	338.1480	0.0000	
R	7.8050	0.2308	33.8139	0.0000	
f1	11.5002	0.2308	49.8227	0.0000	
f2	4.1099	0.2308	17.8057	0.0000	

SUMMARY OUTPUT PHD QUOTA					
Regression Statistics					
Multiple R	0.9960				
R Square	0.9920				
Adjusted R Square	0.9915				
Standard Error	0.2748				
Observations	32.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	272.4739	136.2370	1804.1525	0.0000
Residual	29	2.1899	0.0755		
Total	31	274.6638			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	13.0519	0.0486	268.6812	0.0000	
R	1.3050	0.0486	26.8639	0.0000	
f2	2.6099	0.0486	53.7274	0.0000	

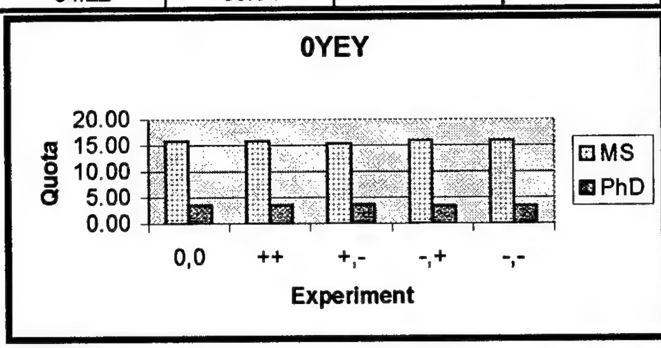
Figure 33: 4Ixx Summary Output / ANOVA

COST ANALYSIS

	Experiment				
4lxx	0,0	++	+,-	-,+	-,-
MS	62.44	57.50	57.50	62.44	62.44
PhD	10.44	12.95	12.95	10.44	10.44
Manyear	124.99	195.55	169.65	72.99	52.10



OYEY	0,0	++	+,-	-,+	-,-
MS	15.84	15.80	15.47	15.96	15.96
PhD	3.49	3.51	3.72	3.43	3.43
Manyear	34.22	53.54	46.11	21.72	14.85



1AGE	0,0	++	+,-	-,+	-,-
MS	16.71	16.71	16.71	16.71	16.71
PhD	0.84	0.84	0.84	0.84	0.84
Manyear	27.59	45.14	43.46	11.72	10.04

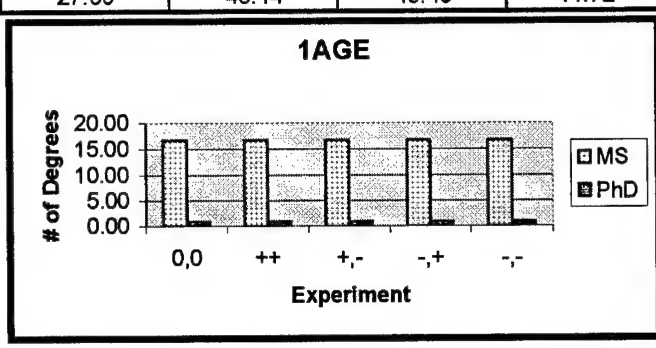


Figure 34: Cost Analysis

4Ixx

SUMMARY OUTPUT MAN-YEARS (Cost Analysis 4Ixx)					
Regression Statistics					
Multiple R	0.9996				
R Square	0.9993				
Adjusted R Square	0.9985				
Standard Error	2.3416				
Observations	5.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	14960.4330	7480.2165	1364.1757	0.0007
Residual	2	10.9666	5.4833		
Total	4	14971.3997			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	123.0545	1.0472	117.5061	0.0001	
MS Cost	60.0274	1.1708	51.2694	0.0004	
PhD Cost	11.6968	1.1708	9.9902	0.0099	
SUMMARY OUTPUT MS QUOTA					
Regression Statistics					
Multiple R	0.9129				
R Square	0.8333				
Adjusted R Square	0.6667				
Standard Error	1.5635				
Observations	5.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	24.4464	12.2232	5.0000	0.1667
Residual	2	4.8893	2.4446		
Total	4	29.3357			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	60.4635	0.6992	86.4710	0.0001	
MS Cost	-2.4722	0.7818	-3.1623	0.0871	
PhD Cost	0.0000	0.7818	0.0000	1.0000	
SUMMARY OUTPUT PHD QUOTA					
Regression Statistics					
Multiple R	0.9129				
R Square	0.8333				
Adjusted R Square	0.6667				
Standard Error	0.7941				
Observations	5.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	6.3056	3.1528	5.0000	0.1667
Residual	2	1.2611	0.6306		
Total	4	7.5667			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	11.4457	0.3551	32.2303	0.0010	
MS Cost	1.2555	0.3970	3.1623	0.0871	
PhD Cost	0.0000	0.3970	0.0000	1.0000	

Figure 35: 4Ixx Cost Analysis Summary Output /ANOVA

0YEY

SUMMARY OUTPUT MAN-YEARS (Cost Analysis 0YEY)					
Regression Statistics					
Multiple R	1.0000				
R Square	0.9999				
Adjusted R Square	0.9998				
Standard Error	0.2268				
Observations	5.0				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1046.0286	523.0143	10171.7558	0.0001
Residual	2	0.1028	0.0514		
Total	4	1046.1314			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	34.0888	0.1014	336.1541	0.0000	
MS Cost	15.7709	0.1134	139.1002	0.0001	
PhD Cost	3.5757	0.1134	31.5379	0.0010	

SUMMARY OUTPUT MS QUOTA					
Regression Statistics					
Multiple R	0.9047				
R Square	0.8186				
Adjusted R Square	0.6371				
Standard Error	0.1217				
Observations	5.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.1336	0.0668	4.5114	0.1814
Residual	2	0.0296	0.0148		
Total	4	0.1632			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	15.8062	0.0544	290.4471	0.0000	
MS Cost	-0.1623	0.0608	-2.6667	0.1165	
PhD Cost	0.0841	0.0608	1.3825	0.3009	

SUMMARY OUTPUT PHD QUOTA					
Regression Statistics					
Multiple R	0.8834				
R Square	0.7804				
Adjusted R Square	0.5609				
Standard Error	0.0781				
Observations	5.0000				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.0434	0.0217	3.5543	0.2196
Residual	2	0.0122	0.0061		
Total	4	0.0556			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	3.5172	0.0349	100.6431	0.0001	
MS Cost	0.0897	0.0391	2.2960	0.1486	
PhD Cost	-0.0530	0.0391	-1.3554	0.3081	

Figure 36: 0YEY Cost Analysis Summary Output / ANOVA

1AGE

SUMMARY OUTPUT MAN-YEARS (Cost Analysis 1AGE)					
Regression Statistics					
Multiple R	1.0000				
R Square	1.0000				
Adjusted R Square	1.0000				
Standard Error	0.0000				
Observations	5.0				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1119.7084	559.8542	58011511753914900000000.0000	0.0000
Residual	2	0.0000	0.0000		
Total	4	1119.7084			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	27.5908	0.0000	198595513395.9790	0.0000	
MS Cost	16.7098	0.0000	107577484198.8440	0.0000	
PhD Cost	0.8420	0.0000	5421000297.9543	0.0000	
SUMMARY OUTPUT MS QUOTA					
Regression Statistics					
Multiple R	0.3848				
R Square	0.1480				
Adjusted R Square	-0.7039				
Standard Error	0.0000				
Observations	5				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	4.701E-21	2.351E-21	1.738E-01	8.520E-01
Residual	2	2.706E-20	1.353E-20		
Total	4	3.176E-20			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	16.70982	0.00000	321244608331.07900	0.00000	
MS Cost	0.00000	0.00000	0.57800	0.62167	
PhD Cost	0.00000	0.00000	0.11578	0.91840	
SUMMARY OUTPUT PHD QUOTA					
Regression Statistics					
Multiple R	0.6144				
R Square	0.3775				
Adjusted R Square	-0.2449				
Standard Error	0.0000				
Observations	5				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	4.6583E-21	2.3292E-21	6.0653E-01	6.2246E-01
Residual	2	7.6803E-21	3.8401E-21		
Total	4	1.2339E-20			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	0.8420	0.0000	30383788333.9922	0.0000	
MS Cost	0.0000	0.0000	-0.9302	0.4505	
PhD Cost	0.0000	0.0000	-0.5898	0.6151	

Figure 37: 1AGE Cost Analysis Summary Output / ANOVA

BIBLIOGRAPHY

1. Brothers, John N., *A Markovian Force Structure Model.* MS Thesis, AFIT/GSA/SM/74-3. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, May 1974.

2. Chrissis, James W. and James T. Moore. "The Advanced Academic Degree Flow Model." Point Paper, School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, August 1998.

3. Dietz, Dennis C. "Satisfying Advanced Degree Requirements for U.S. Air Force Officers," *Military Operations Research,* Volume 2, Number 4: 73-80 (1996).

4. Dietz, Dennis C. US WEST Advanced Technologies. E-mail. 13 October 1998.

5. Dietz, Dennis C. US WEST Advanced Technologies. E-mail. 20 October 1998.

6. Dietz, Dennis C. US WEST Advanced Technologies. E-mail. 11 December 1998.

7. Dietz, Dennis C. "EDFLOW," FORTRAN 77 Code, School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, 1996.

8. Fu, Michael C. and Jian-Qiang Hu. "Operations Research Letters On the Relationship of Capacitated Production/Inventory Models to Manufacturing Flow Control Models," *Operations Research Letters,* 18: 15-24 (1995).

9. Fylstra, Daniel, Leon Lasdon, John Watson, and Allan Waren. "Design and Use of the Microsoft Excel Solver," *Interfaces,* 28: 29-55 (September-October 1998).

10. Hornestay, David. "The People Problem," *Personnel Management,* 32-37, (November 1997).

11. Jackson, Richard, Paul Boggs, Stephen Nash, and Susan Powell. "Guidelines for Reporting Results of Computational Experiments. Report of the Ad Hoc Committee," *Mathematical Programming,* 49: 413-425 (1991).

12. Johnson, K. E., K. W. Bauer, J. T. Moore, and M. Grant, "Metamodelling Techniques in Multidimensional Optimality Analysis for Linear Programming," *Mathematical and Computer Modelling,* 23: 45-60 (1996).

13. Merck, J.W. and Kathleen Hall, *A Markovian Flow Model: The Analysis of Movement in Large-Scale (Military) Personnel Systems.* R-514-PR, RAND, Santa Monica CA, February 1971.

14. McCanne, Randy, *The Airlift Capabilities Estimation Prototype: A Case Study in Model Validation*, MS Thesis, AFIT/GOR/ENS/93M-13. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1993.

15. McGinty, Michael D. Personnel Program Director for Education and Training. Memorandum. 22 March 1995.

16. Myers, Raymond H. and Douglas C. Montgomery. *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*, New York: John Wiley & Sons, Inc., 1995.

17. Neter, John, Michael Kutner, Christopher Nachtsheim, and William Wasserman. *Applied Linear Statistical Models* (Fourth Edition). Chicago: The McGraw-Hill Companies, Inc., 1996.

18. O'Keefe, Robert M., Osman Balci, and Eric Smith. "Validating Expert System Performance," *IEEE Expert*, 2 (4): 81-90 (Winter 1988).

19. Ragsdale Cliff T. *Spreadsheet Modeling and Decision Analysis A Practical Introduction to Management Science*. Cambridge: Course Technology, Inc., 1995.

20. Rish, James C., *A Model for Determining Annual Quotas to Fill Advanced Academic Degree Requirements Within the Civil Engineering Career Field.* LS Thesis, LSSR 52-82, School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1982.

21. Ward, James E. and Richard E. Wendell. "Approaches to Sensitivity Analysis in Linear Programming," *Annals of Operations Research*, 27: 3-38 (1990).

22. Webb, Jeff. *Using Excel Visual Basic For Applications.* Indianapolis: Que Corporation, 1996.

23. Winston, Wayne L. *Operations Research Applications and Algorithms* (Third Edition), Belmont CA: Wadsworth Publishing Company, 1994.

Vita

Major Dave Brown was born on 17 May 1961 in West Chester, Pennsylvania. He graduated from Ridley High School in Ridley Park, Pennsylvania in 1978 and attended Brigham Young University, where he graduated with a Bachelor of Science degree in Mechanical Engineering in April 1984. Upon graduation he received a commission, through AFROTC, in the USAF and attended Undergraduate Navigator Training at Mather AFB, California. He graduated number one in his class and received the ATC Commander's Trophy and the Ira J. Husik award in November of 1984. He was assigned to fly the E-3 at Tinker AFB, Oklahoma, where he quickly progressed from line navigator, through Initial Qualification Training Instructor and Flight Evaluator. In 1989, he was selected as the Standardization and Evaluation Flight Examiner Navigator for the 961 AWACS at Kadena AB, Japan. In 1992, he was chosen as initial cadre to Mt. Home AFB, Idaho where he was attached to the newly formed, composite, 366 WG as the Wing Staff Navigator and Chief of Wing Scheduling. In 1994, he was sent to Joint Undergraduate Navigator Training as a radar navigation instructor and ADO of the 562 FTS, where he was responsible for the training of over 300 USAF navigators and USN Flight Officers per year. Major Brown entered the Graduate School of Engineering of the Air Force Institute of Technology in August 1997.

Permanent Address: 700 Thayer St.
Ridley Park, PA 19078

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13. ABSTRACT *(Maximum 200 words)*

One of the many needs of the Air Force is advanced technical degrees. These degrees can be acquired in three ways: the Air Force can directly recruit personnel with the required degrees; Air Force personnel can obtain them during off duty time from local civilian colleges near their base; or the Air Force can provide advanced academic degrees (AADs) through the Air Force Institute of Technology (AFIT) or AFIT-sponsored programs.

In 1995, the AFIT Commandant initiated a re-engineering study to review the AFIT mission. One of the initiatives of that study was the Quota Allocation Model (QuAM). The QuAM model is a two-phase mathematical model based on a Markov process that is used to feed a linear optimization. Outputs from the model provide the minimum number of officers, by grade and academic specialty, that must be educated annually to meet the needs and requirements of the Air Force in each of the Air Force education codes. This thesis effort entails: developing a user-friendly tool; migrating the model from lines of FORTRAN 77 code to an Excel spreadsheet environment; highlighting the assumptions necessitated by the Markov decision process; and testing for sensitivity to variations in model input parameters (AAD requirements, attrition, and inventory factors).

14. SUBJECT TERMS
Linear Optimization, Markov Process, Spreadsheet Modeling, Personnel Modeling, Mathematical Modeling, Sensitivity Analysis

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